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MEMORANDUM REPORT ARBRL-MR-03123

AUTOMATIC PLOTTING ROUTINES FOR ESTIMATING STATIC AERODYNAMIC PROPERTIES OF LONG ROD FINNED PROJECTILES FOR 2<M<5

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August 1981

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BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Drag
Static Moment
Caliber notation

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A predictive program for the estimation of static aerodynamic coefficients for long rod projectiles at 2<M<5 is presented in desk top (Tektronix 4051) computer context. The technique is demonstrated by application to a typical projectile for which range data is available for comparison.

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I. INTRODUCTION

The aerodynamics of long rod finned projectiles has been surveyed by many investigators[1,2,3,4,5,6,7,8] with principal efforts directed to resolving the individual contributions of the component hardware (nose, body and tail) in the determination of the static aerodynamic coefficients. Only rarely has the trajectory problem been addressed, although the specific analysis of the dispersion of the projectile at the target has been examined carefully in the open literature[9,10]. Previous searches for predictive algorithms considering the complete free-flight package were not rewarding; and this led to the issue of several additional

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[1] *C.H. Murphy, "Free Flight Motion of Symmetric Missiles", BRL Report No. 1216, July 1963 (AD #442757).*

[2] *AMCP 706-280, "Design of Aerodynamically Stabilized Free Rockets", 1968.*

[3] *W.F. Braun, "Aerodynamic Data for Small Arms Projectiles", BRL Report No. 1630, January 1973 (AD #909757L).*

[4] *H.W. Liepmann and A. Roshko, Element of Gasdynamics, John Wiley and Sons, Inc., New York, 1957.*

[5] *A.H. Shapiro, The Dynamics and Thermodynamics of Compressible Fluid Flow, Volume I, The Ronald Press Company, New York, 1953.*

[6] *M. Piddington, "The Aerodynamic Characteristics of a SPIW Projectile", BRL Memorandum Report No. 1594, September 1964 (AD #355679L).*

[7] *E.R. Dickenson, "Some Aerodynamic Effects of Blunting a Projectile Nose", BRL Memorandum Report No. 1596, September 1964 (AD #451977L).*

[8] *L.C. MacAllister, "Drag and Stability Properties of the XM144 Flechette with Various Head Shapes", BRL Memorandum Report No. 1981, May 1969 (AD #854724).*

[9] *W.J. Gallagher, "Elements Which Have Contributed to Dispersion in the 90/40 mm Projectile", BRL Report No. 1013, March 1957 (AD #135306L).*

[10] *J.D. Nicolaides, C.W. Ingram, "Analysis of the Jump and Dispersion of Flechettes", Prepared for U.S. Army, Frankford Arsenal under Contract No. DAAA 25-71-C0447.*

constituant reports[11,12,13,14,15] which, however, had the ultimate objective of composing a more comprehensive publication which would enhance estimating facility for this particular class of flight projectile.

This report is an attempt to scribe the envelope of the preliminary design configuration. The drag, static moment and normal force coefficients are determined from the simplified geometry of the projectile and the bounding aerodynamics conditions; i.e., sea level flat fire, 2<M<5 and low yaw as developed in the previous reports[11,14] with the accuracy factor (related to the dispersion) and retardation similarly extracted[12,13]. The program is written in Tektronix 4051 Basic language with graphic extensions. The program flowchart, sample graphics screen display and program listing are given in Appendices A, B, and C, respectively.

The example provided for illustration has not been extensively flight tested; indeed, a complete set of data to include range aerodynamics, retardation and dispersion for a given projectile over the selected Mach excursion is simply not available. The influence of the dynamic aerodynamic coefficients, the damping and the Magnus, on the flight performance is even more difficult to certify. However, what disparate data that is published does suggest that the given criteria for design are viable. It is also obvious that local modifications to the program, based on individual experience, are certainly inevitable and are actively encouraged.

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[11] W.F. Donovan, *"Procedure for Estimating Zero Yaw Drag Coefficient for Long Rod Projectiles at Mach Numbers from 2 to 5", BRL Memorandum Report No. ARBRL-MR-02819, March 1978 (AD #A054326).*

[12] W.F. Donovan, *"One Factor Affecting the Dispersion of Long Rod Penetrators", BRL Memorandum Report No. ARBRL-MR-02846, June 1977 (AD #A058596).*

[13] W.F. Donovan, *"Simplified Determination of Retardation for Kinetic Energy Projectiles", BRL Memorandum Report No. ARBRL-MR-02994, February 1980 (AD #083299).*

[14] W.F. Donovan, *"Algorithm for Estimating Aerodynamic Static Moments of Long Rod Penetrators at 2<M<5," BRL Memorandum Report No. ARBRL-MR-03020, May 1980 (AD #086095).*

[15] W.F. Donovan, *"Hypothetical Zero Yaw Drag Coefficient of Kinetic Energy Projectiles Between M = 5 and M = 10", BRL Memorandum Report No. ARBRL-MR-03041, August 1980 (AD # 090009).*

II. PROCEDURE

The analytic expressions for the various parameters are taken from the previous reports and tabulated. Recent test results have been used to modify the equations, where indicated, to improve correspondence between test and prediction. The fin-body interference factor has been adjusted to recognize a fin masking effect of the boundary layer and a separate drag contribution has been assigned to the presence of the driving grooves. Caliber notation, where a representative linear dimension provides a reference length and the mass/force dimension is converted to a specific gravity equivalent, is employed extensively. This rather novel practice allows a direct comparison of projectile performance on the basis of a "ballistic weight" quite independent of physical dimension.

Figure 1 is an outline of a typical long rod projectile. Tables 1, 2 and 3 contain the equations used in developing the programs. The initialization instructions are presented in Appendix A and the full program listings follow. The program provides an outline plot of the projectile with the physical properties and gives a complete chart description of the aerodynamic coefficients with accuracy factor, decrementing velocity and initial yaw cycle estimates. The accompanying print-out lists the discrete component contributions and the retardation over the expected range of the flight to M = 5.

III. RESULTS

The 25/12 projectile, recently tested in the BRL aerodynamics range, is used to demonstrate the working procedure. Figure 2 is a photograph of the flight assembly and Table B contains the input for the programs. The program provides hard copy computer prints of the projectile outline, Figure 3, and the corresponding estimated aerodynamic performance, Figures 4 through 8. Table 4 is a summary of the results.

The available range data is superposed by an asterisk.

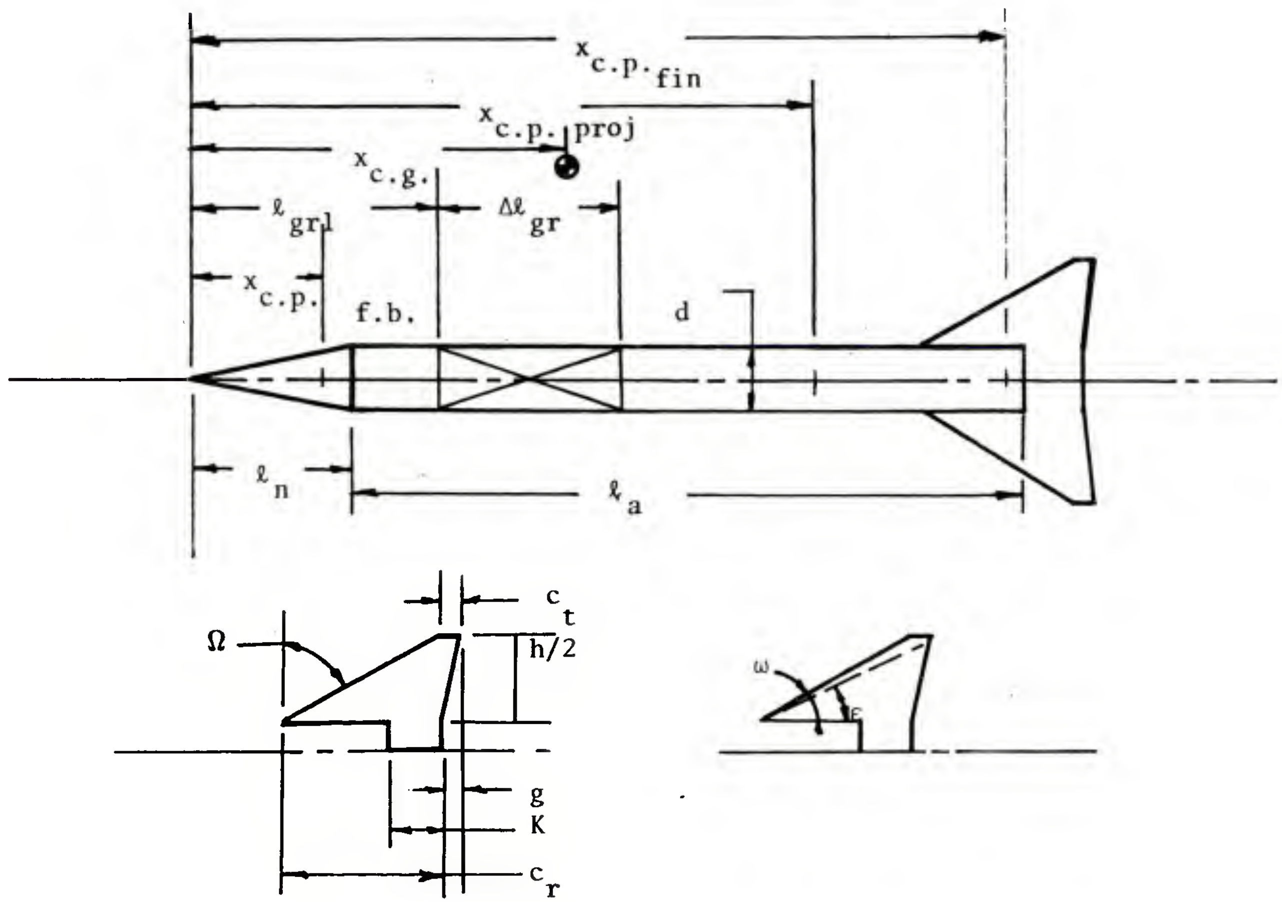


Figure 1. Outline of Long Rod Projectile

TABLE 1. SYNTHESIS OF DRAG COEFFICIENT EQUATIONS

		DRAG COEFFICIENT
Body	Wave	$C_{CWB} = .7M^{-.28} \ell_n^{-1.73}$
	Base	$C_{DBB} = -\ .048M + .265$
	Viscous	$C_{DVB} \doteq .000173\ (28.75-4.166M)\ \dfrac{A_{wetted\ body}}{A_{ref}}$
	Subtotal	$C_{DTB} = C_{DWB} + D_{DBB} + C_{DVB}$
Fin	Wave	$C_{DWF} = \left(\dfrac{n}{\beta}\right)\left(\dfrac{t}{j}\right)^2 \dfrac{A_{wetted\ fin}}{A_{ref}}$
	Base	$C_{DBF} = \dfrac{A_{Base\ Fin}}{A_{Base\ Body}}\ C_{DBB}$
	Fin	$C_{DVF} = \dfrac{1}{1.15}\left(\dfrac{A_{Wetted\ Fin}}{A_{Wetted\ Body}}\right) C_{DVB}$
	Subtotal	$C_{DTF} = C_{DWF} + C_{DBF} + C_{DVF}$
Assembly	Grooves	$C_{DGR} = .00025\ M^{3.9}\ \Delta\ \ell_{gr}\ C_{DTB}$
	Total	$C_{DT} = C_{DTB} + C_{DTF} + C_{DGR}$

TABLE 2. SYNTHESIS OF NORMAL FORCE AND STATIC MOMENT SLOPE COEFFICIENT EQUATIONS

Normal Force and Static Moment Coefficients[14]			
Nose Datum	Body	Normal Force Coefficient	$C_{N\alpha B} \left(1.9 + 1.3 \frac{\beta}{\ell_n} + .0149 \frac{\ell_a}{\beta}\right)\left(\beta^{-.7}\right)\left(-.0675\ell_T + 2.3\right)$
		Center of Pressure of Normal Force	$x_{c.p.B} = \left(.69 + .65 \frac{\beta}{\ell_n} + .5 \frac{\ell_a}{\beta}\right)\left(\beta^{-.46}\right)$
		Static Moment Coefficient	$C_{M\alpha B} = \left(x_{c.p.B}\right)\left(C_{N\alpha B}\right)$
	Fins	Normal Force Coefficient	$C_{N\alpha F} = \eta\left\{\left[4 + \left(.9\lambda + \frac{5}{4} \log_e \left(\frac{AR\,TAN\Omega}{4}\right)\right)\left(\frac{TAN\Omega}{\beta}\right)\right] + \frac{\Omega}{TAN\Omega}\left[\left(.6AR-1\right)\left(1 - \frac{\beta}{TAN\Omega}\right)\right]\left[\frac{.541}{M}\right]\left[\beta^{-.58}\right]\right\}\frac{A_{\text{Wetted fin}}}{\pi}$
		Center of Pressure of Normal Force	$x_{c.p.F} = \ell_n + \ell_a + k - \left(\frac{c_r + g}{2}\right)$
		Static Moment Coefficient	$C_{M\alpha F} = x_{c.pF} \quad C_{N\alpha F}$
		Interference Factor	$K = (-.167\, a + 1.334)e^{d/d + h} \left(\frac{9}{\ell_a}\right)$
	Assembly	Normal Force Coefficient	$C_{N\alpha} = C_{N\alpha B} + KC_{N\alpha F}$
		Static Moment Coefficient	$C_{M\alpha} = C_{M\alpha B} + KC_{M\alpha F}$
		Center of Pressure of Normal Force	$x_{c.p.} = C_{M\alpha}/C_{N\alpha}$
Gravity Datum	Assembly	Normal Force Coefficient	$C_{N\alpha} = C_{N\alpha}$
		Center of Pressure of Normal Force	$x_{c.p.} = x_{c.p.}$
		Static Margin	$\Delta x = x_{c.p.} - x_{c.g.}$
		Static Moment Coefficient	$C_{M\alpha} = (x_{c.p.} - x_{c.g.})\ (C_{N\alpha})$

TABLE 3. RETARDATION, ACCURACY FACTOR AND INITIAL YAW EQUATIONS

Retardation[13]	
Mach Number along Trajectory	$M_1 = \dfrac{b}{R\ e^{Qs} - c}$
Average Velocity Decrement	$\Delta v = \dfrac{M_0 - M_1}{s}\ (v)_{sonic}$
Accuracy Factor[12]	
Accuracy Factor	$J_\zeta = \dfrac{C_{L\alpha}}{C_{M\alpha}}\ \dfrac{I_y}{md^2}$
Initial Yaw Period[12]	
Peak to Peak Distance	$\Delta s = \pi \left[\dfrac{2\ I_y}{\rho A_{ref} C_{M\alpha} d} \right]^{1/2}$

Figure 2. Photograph of 25/12 Projectile

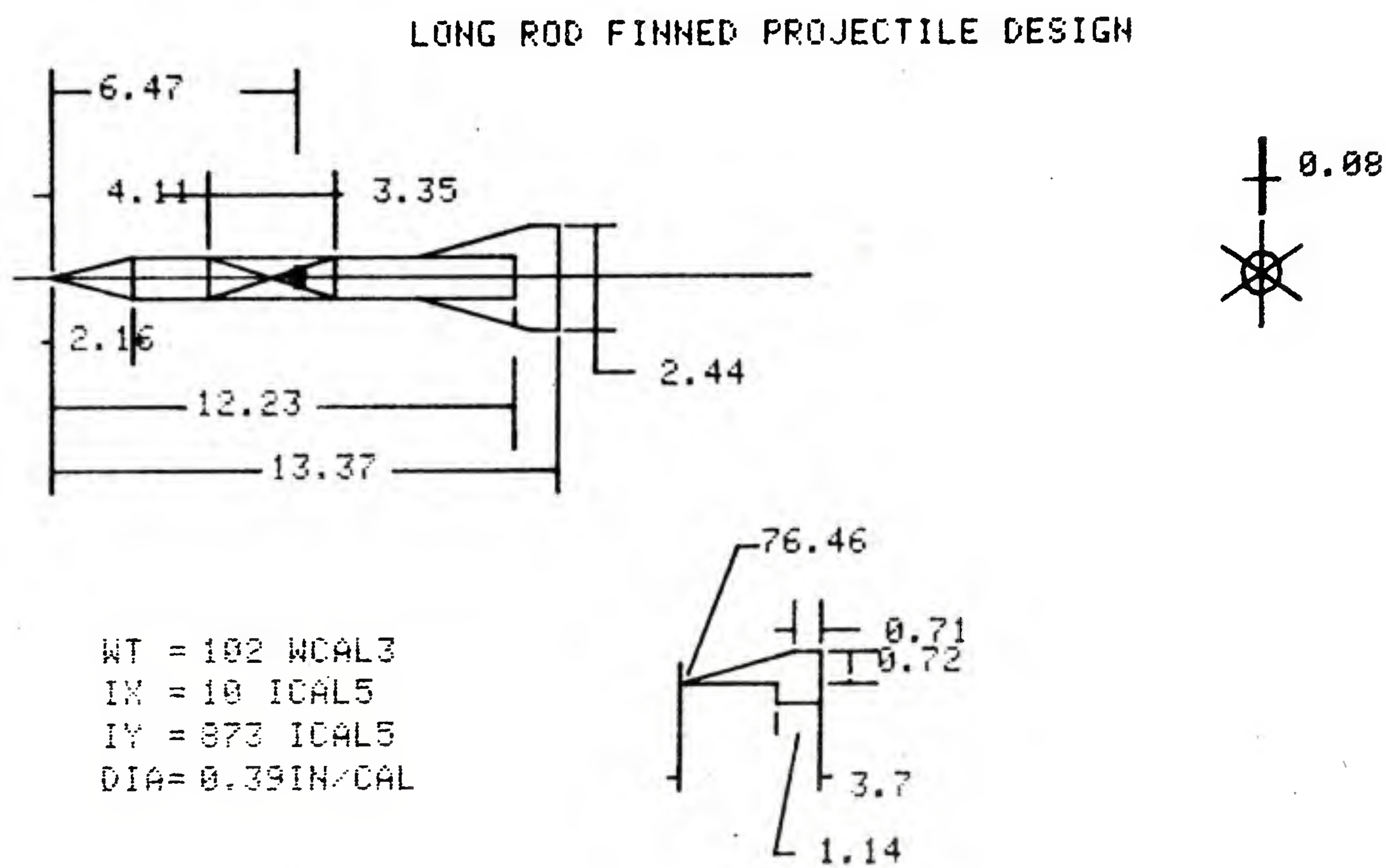


Figure 3. Outline of 25/12 Projectile

TABLE 4. SUMMARY OF CALCULATED AERODYNAMIC COEFFICIENTS

	MACH NUMBER						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
CNAB	3.041	2.760	2.603	2.505	2.440	2.396	2.365
XCPB	3.199	2.443	2.059	1.834	1.693	1.599	1.537
CMAB	9.726	6.742	5.359	4.595	4.130	3.832	3.635
CNAF	1.000	1.009	0.931	0.849	0.775	0.711	0.655
CNAT	17.130	16.715	15.249	13.835	12.602	11.550	10.653
CMAT	172.040	167.503	151.039	135.113	121.194	109.287	99.114
CG-CP	-3.573	-3.551	-3.435	-3.296	-3.147	-2.992	-2.833
CMAT,CG	-61.206	-59.357	-52.379	-45.602	-39.660	-34.559	-30.186
CDWB	0.152	0.143	0.136	0.130	0.125	0.121	0.118
CDBB	0.169	0.145	0.121	0.097	0.073	0.049	0.025
CDVB	0.191	0.172	0.152	0.133	0.113	0.094	0.074
CDGRV	0.006	0.014	0.025	0.040	0.058	0.078	0.097
CDTB	0.513	0.460	0.409	0.360	0.312	0.264	0.217
CDWF	0.006	0.005	0.004	0.003	0.003	0.003	0.002
CDBF	0.074	0.064	0.053	0.043	0.032	0.022	0.011
CDVF	0.008	0.008	0.007	0.006	0.005	0.004	0.003
CDTF	0.089	0.076	0.064	0.052	0.040	0.028	0.017
CDT	0.608	0.550	0.498	0.452	0.410	0.370	0.330
CLA	16.522	16.165	14.751	13.383	12.192	11.180	10.323
J ZETA	-2.310	-2.331	-2.410	-2.512	-2.631	-2.769	-2.927

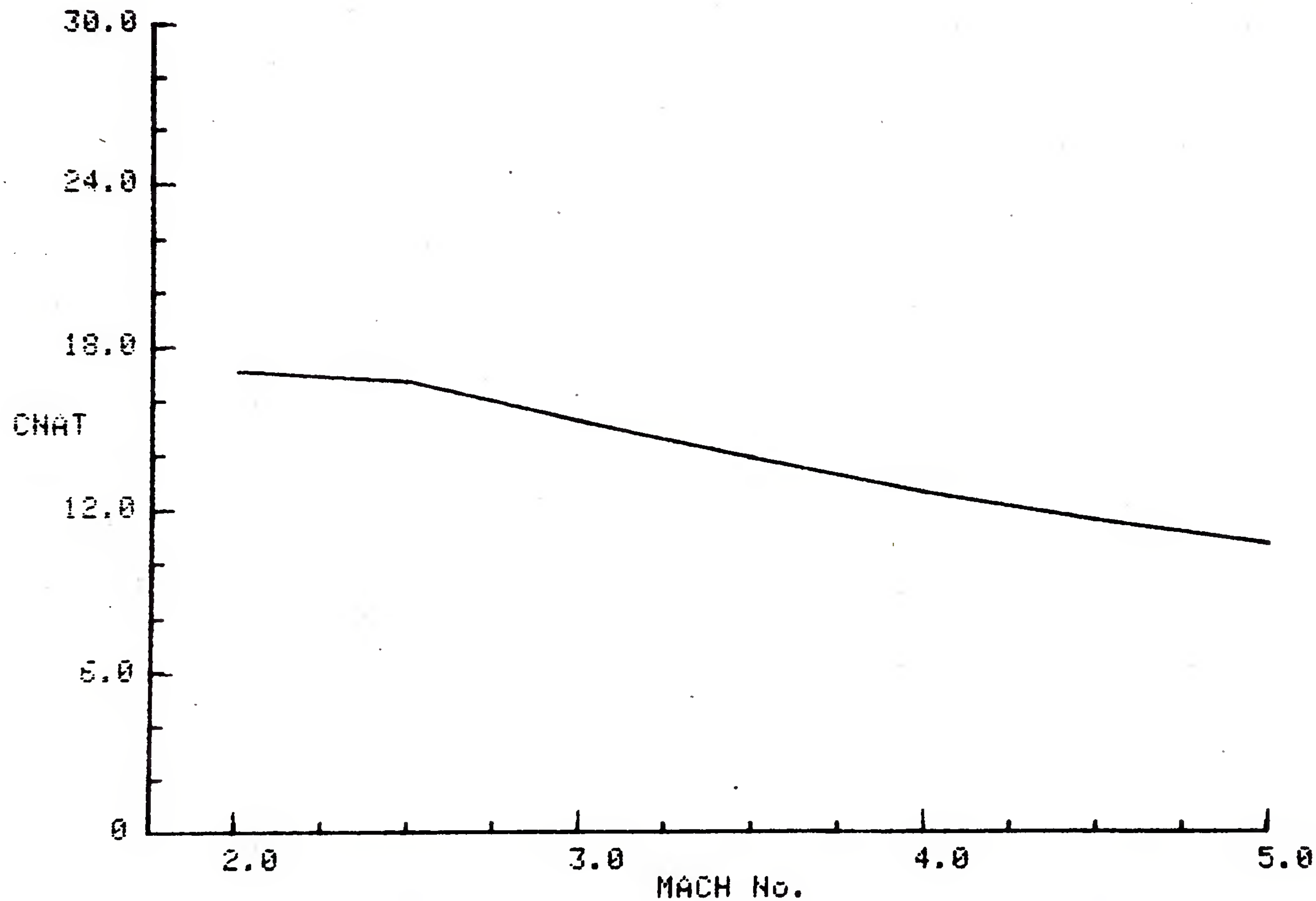


Figure 4. Normal Force Slope Coefficient vs Mach Number

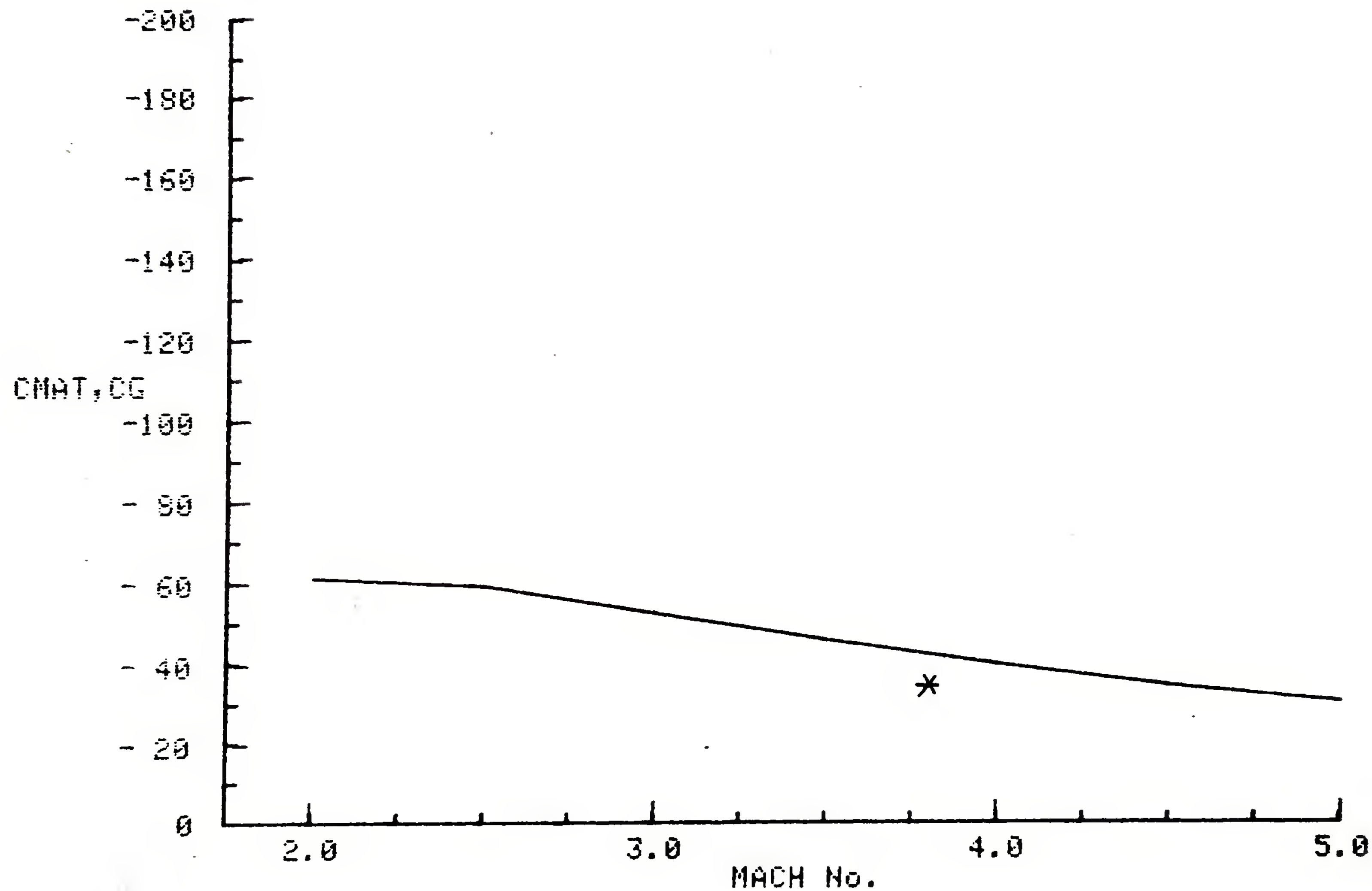


Figure 5. Static Moment Slope Coefficient vs Mach Number

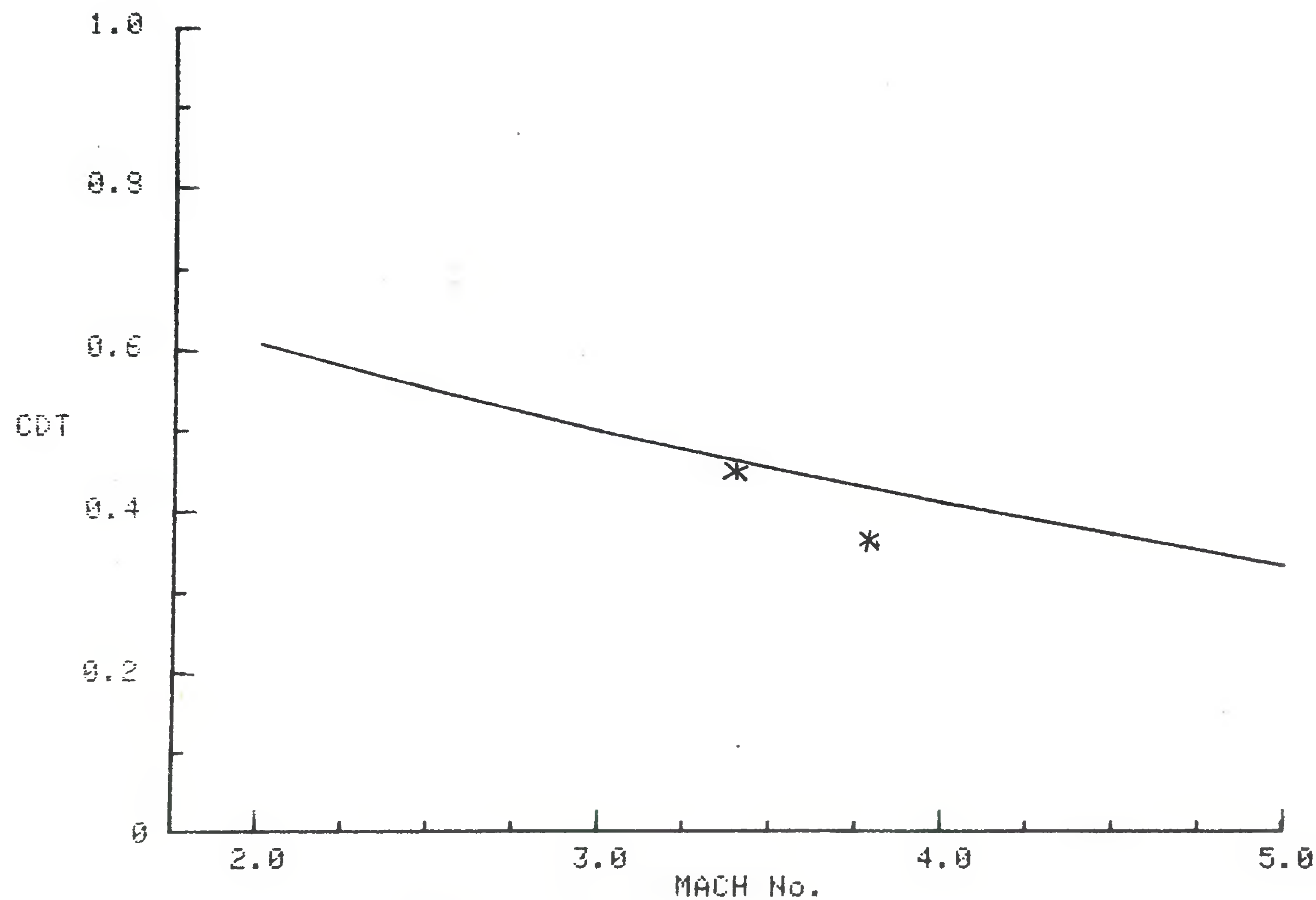
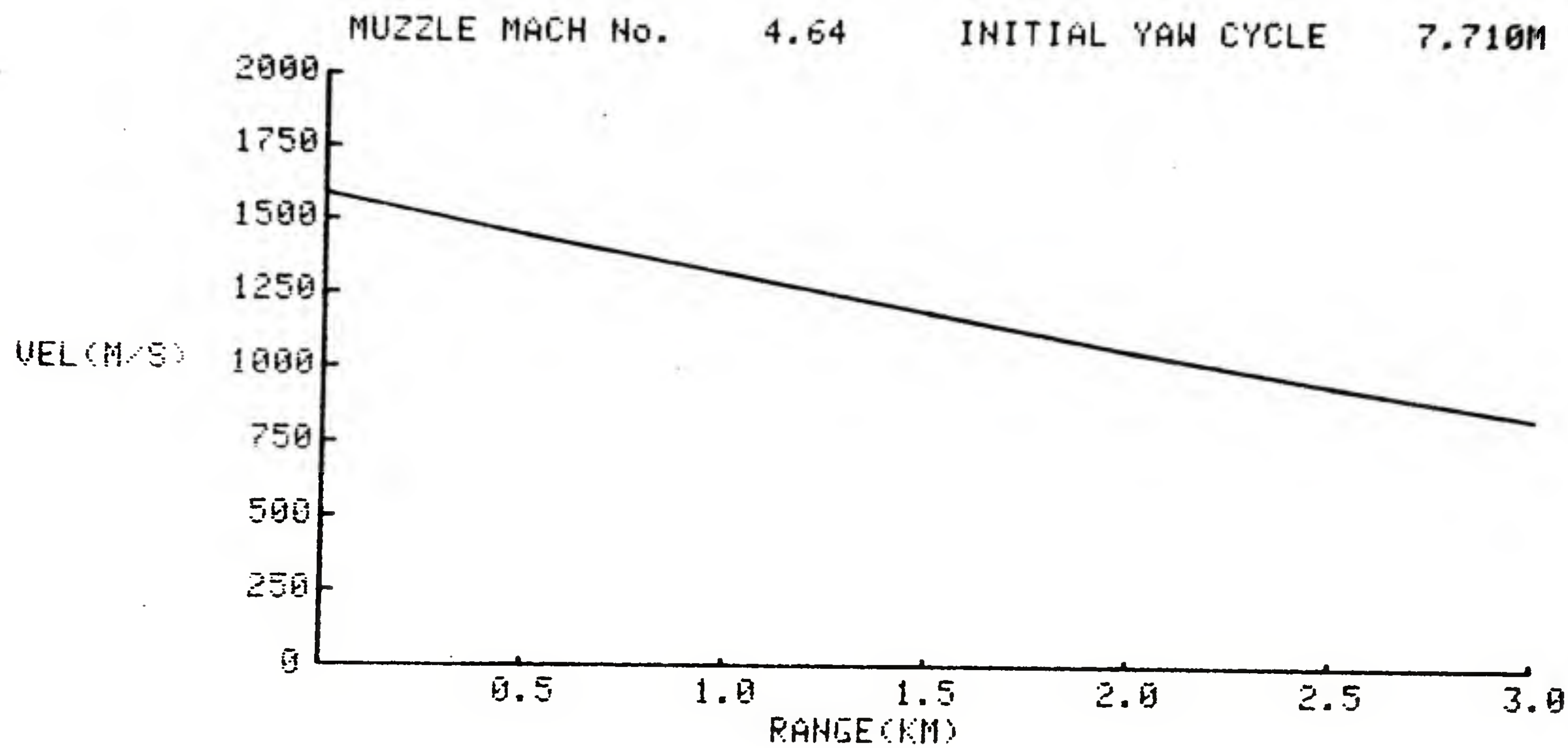


Figure 6. Zero Yaw Drag Coefficient vs Mach Number



RANGE	3000 M	RETARDATION	249.182 M/S/KM
RANGE	2500 M	RETARDATION	254.867 M/S/KM
RANGE	2000 M	RETARDATION	259.616 M/S/KM
RANGE	1500 M	RETARDATION	263.274 M/S/KM
RANGE	1000 M	RETARDATION	265.714 M/S/KM
RANGE	500 M	RETARDATION	266.845 M/S/KM
RANGE	0 M	RETARDATION	266.845 M/S/KM

Figure 7. Velocity Decrement and Retardation vs Range

ACKNOWLEDGMENTS

Mr. Basil Reiter of the Launch and Flight Division undertook the arduous task of the final transposition of the original Hewlett-Packard 9820-A listing into the current Tektronix 4051 listing presented in the report.

REFERENCES

1. C.H. Murphy, "Free Flight Motion of Symmetric Missiles", BRL Report No. 1216, July 1963 (AD #442757)

2. AMCP 706-280, "Design of Aerodynamically Stabilized Free Rockets", 1968.

3. W.F. Braun, "Aerodynamic Data for Small Arms Projectiles", BRL Report No. 1630, January 1973 (AD #909757L)

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9. W.J. Gallagher, "Elements Which Have Contributed to Dispersion in the 90/40 mm Projectile", BRL Report No. 1013, March 1957 (AD #135306)

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13. W.F. Donovan, "Simplified Determination of Retardation for Kinetic Energy Projectiles", BRL Memorandum Report No. ARBRL-MR-02994, February 1980 (AD #083299).

14. W.F. Donovan, "Algorithm for Estimating Aerodynamic Static Moments of Long Rod Penetrators at 2<M<5", BRL Memorandum Report No. ARBRL-MR-03020, May 1980 (AD #086095).

REFERENCES (continued)

15. W.F. Donovan, "Hypothetical Zero Yaw Drag Coefficient of Kinetic Energy Projectiles Between M = 5 and M = 10", BRL Memorandum Report No. ARBRL-MR-03041, August 1980 (AD #090009).

LIST OF SYMBOLS

A	β TAN ω , operational parameter
b	Intercept of C_D vs M characteristic
c	Slope of C_D vs M characteristic
c_r	Fin blade length at root
c_t	Fin blade length at tip
c.g.	Center of gravity of projectile, nose datum
c.p.	Center of pressure of normal force
d	1.0 cal , reference diameter
e	Base of Natural log
g	Fin dimension (root recess)
$h/2$	Fin dimension (blade height)
j	Fin dimension (blade slant height)
k	Fin dimension (blade extension from body)
ℓ_a	Cylindrical body length
ℓ_{gr1}	Groove length from nose (starting groove)
ℓ_{gr2}	Groove length from nose (last groove)
$\Delta\ell_{gr}$	Groove length
ℓ_n	Nose length
$\ell_{o.a.}$	Overall length of projectile
ℓ_T	$\ell_a + \ell_n$
m	Mass of projectile
n	Number of fin blades
s	Range
t	Fin dimension (average thickness)
v	Velocity of projectile

LIST OF SYMBOLS (continued)

Δv	Velocity decrement over specified range
x	Distance along projectile, nose datum
AR	h^2/S_F, Aspect ratio of fin planform
$A_{base\ body}$	Area of body exposed to base pressure $(cal)^2$
$A_{base\ fin}$	Area of fin exposed to base pressure $(cal)^2$
A_{ref}	Reference area (.785 cal^2)
$A_{wetted\ body}$	Area of body producing viscous flow drag
$A_{wetted\ fin}$	Area of fin producing viscous flow drag
C_D	$\dfrac{\text{Drag Force}}{\frac{1}{2}\rho v^2 A_{ref}}$, zero-yaw drag coefficient
C_{DBB}	Pressure drag coefficient - base of body
C_{DBF}	Pressure drag coefficient - base of fins
C_{DGR}	Drag coefficient due to grooves
C_{DT}	Total drag coefficient
C_{DTB}	Total body drag coefficient
C_{DTF}	Total fin drag coefficient
C_{DVB}	Viscous drag coefficient - body
C_{DVF}	Viscous drag coefficient - fins
C_{DWB}	Wave drag coefficient - body (nose)
C_{DWF}	Wave drag coefficient - fin
$C_{L\alpha}$	$\dfrac{\text{Lift Force}}{\frac{1}{2}\rho v^2 A_{ref}\ \delta}$, aerodynamic lift slope coefficient, $\delta = \sin \alpha_T$
$C_{M\alpha}$	$\dfrac{\text{Static Moment}}{\frac{1}{2}\rho v^2 A_{ref}\ d\delta}$, aerodynamic moment slope coefficient

$C_{M\alpha B}$	Static moment coefficient - body
$C_{M\alpha F}$	Static moment coefficient - fins
$C_{N\alpha}$	$\dfrac{\text{Normal Force}}{\frac{1}{2}\,\rho\, v^2\, A_{ref}\,\delta}$, aerodynamic normal force slope coefficient
$C_{N\alpha B}$	Normal force coefficient - body
$C_{N\alpha F}$	Normal Force coefficient - fins
I_x	Axial moment of inertia
I_y	Transverse moment of inertia
J_ζ	$\dfrac{I_y}{md^2}\,\dfrac{C_{L\alpha}}{C_{M\alpha}}$, aerodynamic jump factor
K	Interference factor
M	Mach number
M_0	Mach number at muzzle
M_1	Mach number along trajectory
Q	Operational parameter, $\dfrac{\rho\, A_{ref}\, b}{2\, m}$
R	Operational parameter, $\dfrac{c\, M_o + b}{M_o}$
α	Angle of attack, employed here as a subscript
β	$(M^2 - 1)^{1/2}$, operational parameter
δ	sine of total angle of attack
ζ	Dispersion parameter, employed here as a subscript
λ	c_t/c_r, fin tip ratio
π	3.1416

LIST OF SYMBOLS (continued)

ρ	Ambient air density
Ω	Fin sweep angle

APPENDIX A

INITIALIZATION INSTRUCTIONS

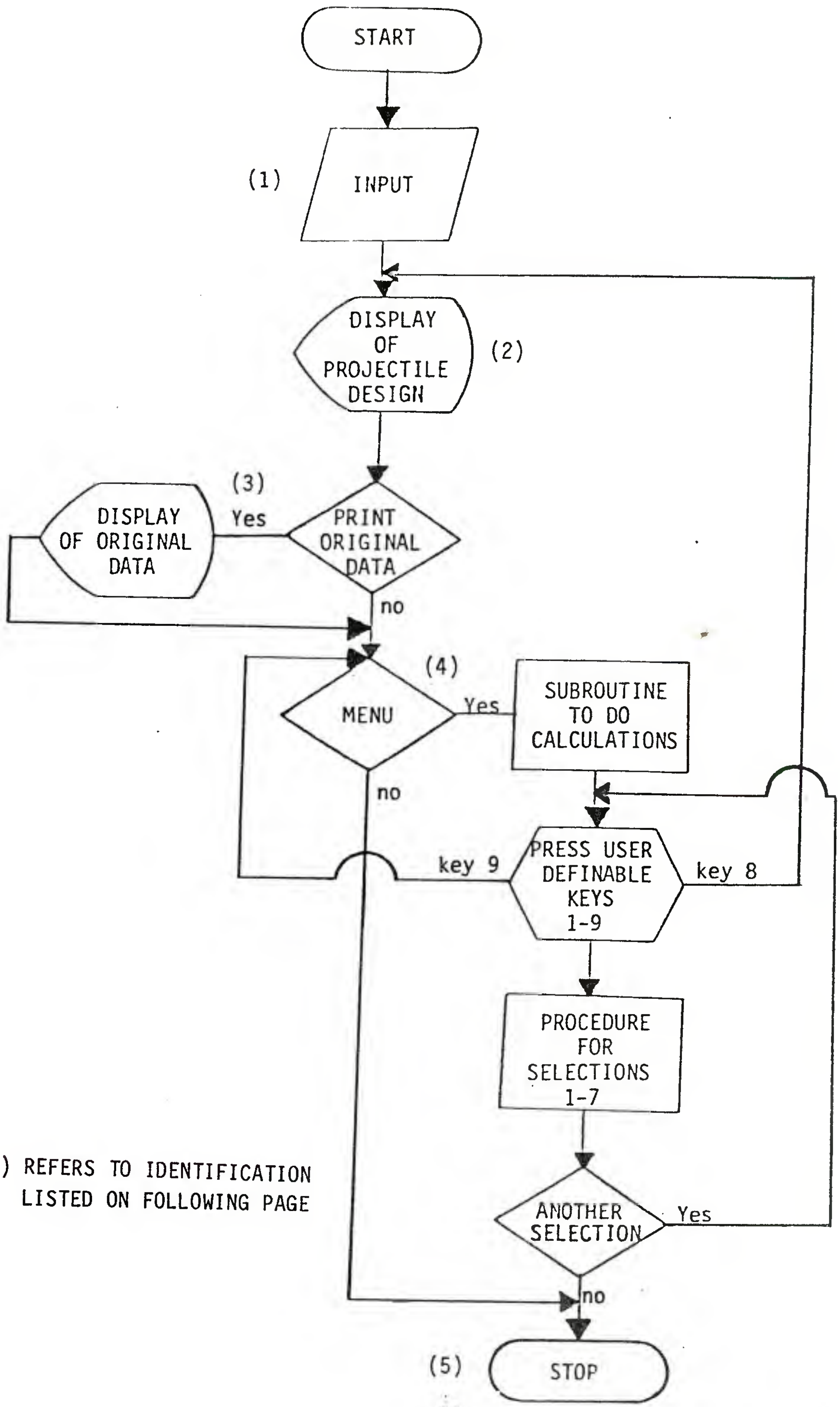
APPENDIX A

INITIALIZATION INSTRUCTIONS

Initialization requires only the entry of the geometry and physical properties of the projectile, the range excursion and the muzzle Mach number as directed by the program listing according to the following schedule.

Tektronix Nomenclature	Figure 1 Identification	Notes
L	ℓ_n	Refers to equivalent[16] conical nose length
L1	ℓ_a	Includes cylindrical length of body to which fins are attached. A taper hub is approximated as a cylinder of half the length of the taper. A shallow taper aft body (BM6) requires an engineering evaluation.
P1	ℓ_1 groove	Distance to start of groove. Nose datum.
P2	$\Delta\ell$ groove	Length of groove set.
H2	$h/2$	Radial fin length above hub.
C	c_r	
G	g	
K	k	
T	t	Taken as maximum thickness of fin blade.
C1	c_t	
N	n	Restricted to either four or six blades in static moment calculation. Unrestricted in drag calculation.
C2	c.g.	Nose datum.
M0	M_0	Muzzle Mach number.
S	s_{max}	Maximum range in meters
W	wt.	
I	I_x	
I1	I_y	
D	d	May be given in either inches or millimeters.

FLOWCHART FOR AUTOMATIC PLOTTING ROUTINES



( ) REFERS TO IDENTIFICATION LISTED ON FOLLOWING PAGE

IDENTIFICATION OF FLOWCHART STEPS

(1) Program Inputs: (All values are to be inputted in calibers unless otherwise noted)

A - Number of Fins (4 or 6)
B - Conical Nose Length
C - Cylindrical Body Length
D - Groove Location/Nose
E - Groove Length
F - Fin Dimension (Blade Height)
G - Fin Blade Length at Root
H - Fin Dimension (Root Recess)
I - Fin Dimension (Blade Extention from Body)
J - Fin Dimension (Maximum Thickness)
K - Fin Blade Length at Tip
L - Center of Gravity of Projectile
M - 1.0 Caliber Reference Diameter (Millimeters or Inches)
N - Normalized Weight of Projectile (Cal^3)
O - Axial Moment of Inertia (Cal^5)
P - Transverse Moment of Inertia (Cal^5)
Q - Mach Number at Muzzle
R - Maximum Range (Meters, < 4000)
S - Plotting Device Number (1=Pen Plotter, 32=Screen)

(2) Projectile Design: Rear and Profile Views of Projectile and Fin

(3) Optional Printout of Original Data

(4) Program Selection: (Use User Definable Key)

A - Nomenclature -- A Listing of Aerodynamic Coefficients and their Definitions (Key 1)
B - Table of Coefficients -- A Listing of the Aerodynamic Coefficients and Definitions (Key 2)
C - Total Normal Force Coefficient ($C_{n_{\alpha t}}$) versus Mach Number Plot (Key 3)
D - Total Drag Coefficient (C_{D_T}) versus Mach Number Plot (Key 4)
E - Velocity versus Range Plot (Key 5)
F - Total Pitching Moment about the Center of Gravity ($C_{m_{\alpha t}}$, CG) versus Mach Number Plot (Key 6)
G - Aeordynamic Jump Factor (J_ζ) versus Mach Number Plot (Key 7)
H - Reprint of Projectile Design (Key 8)
I - Return to Menu (Key 9)

(5) Stop

APPENDIX B

SAMPLE GRAPHICS SCREEN DISPLAY

```
THIS PROGRAM WILL CALCULATE AND PLOT ESTIMATED STATIC AERODYNAMIC
 COEFFICIENTS OF LONG ROD FINNED PROJECTILES FOR 2<M<5

INPUT NUMBER OF FINS (4 or 6): 6

INPUT THESE VALUES IN CALIBERS

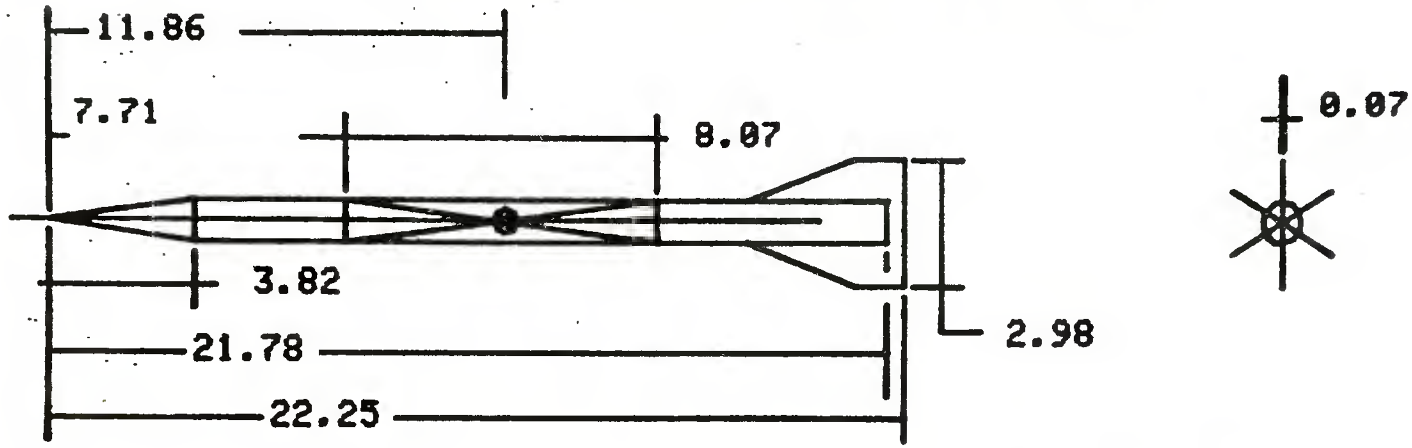
INPUT CONICAL NOSE LENGTH: 3.82
INPUT CYLINDRICAL BODY LENGTH: 17.96
INPUT GROOVE LOCATION/NOSE: 7.71
INPUT GROOVE LENGTH: 8.07
INPUT FIN DIMENSION (BLADE HEIGHT): .99
INPUT FIN BLADE LENGTH AT ROOT: 4.11
INPUT FIN DIMENSION (ROOT RECESS): 0
INPUT FIN DIMENSION (BLADE EXTENSION FROM BODY): .47
INPUT FIN DIMENSION (MAXIMUM THICKNESS): .07
INPUT FIN BLADE LENGTH AT TIP: 1.31
INPUT CENTER OF GRAVITY OF PROJECTILE : 11.86
INPUT 1.0 CALIBER REFERENCE DIAMETER (MILLIMETERS): 0
INPUT 1.0 CALIBER REFERENCE DIAMETER (INCHES): 1.07
INPUT NORMALIZED WEIGHT OF PROJECTILE (CAL↑3): 194
INPUT AXIAL MOMENT OF INERTIA(CAL↑5): 23
INPUT TRANSVERSE MOMENT OF INERTIA(CAL↑5): 4975

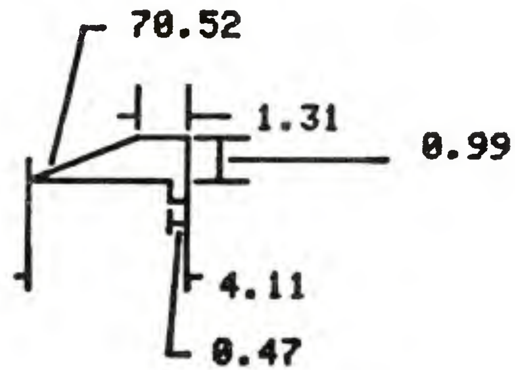
INPUT THESE RANGE VALUES

INPUT MACH NUMBER AT MUZZLE: 4.732
INPUT MAXIMUM RANGE (METERS, (=4000): 3000

INPUT PLOTTING DEVISE NUMBER(1=PEN PLOTTER,32=SCREEN): 32
```

LONG ROD FINNED PROJECTILE DESIGN





WT =   194 WCAL3
IX =   23 ICAL5
IY =   4975 ICAL5
DIA=   1.07IN/CAL

IF YOU WANT THE INITIAL DATA PRINTED OUT ENTER 'YES':

```
ALL VALUES ARE IN CALIBERS UNLESS OTHERWISE NOTED

CONICAL NOSE LENGTH:  3.82
CYLINDRICAL BODY LENGTH:  17.96
GROOVE LOCATION/NOSE:  7.71
GROOVE LENGTH:  8.07
FIN DIMENSION (BLADE HEIGHT):  0.99
FIN BLADE LENGTH AT ROOT:  4.11
FIN DIMENSION (ROOT RECESS):  0
FIN DIMENSION (BLADE EXTENSION FROM BODY):  0.47
FIN DIMENSION (MAXIMUM THICKNESS):  0.07
FIN SWEEP ANGLE (DEGREES):  70.52
FIN BLADE LENGTH AT TIP:  1.31
NUMBER OF BLADES:  6
CENTER OF GRAVITY:  11.86
MACH NUMBER AT MUZZLE:  4.732
MAXIMUM RANGE (METERS):  3000
WEIGHT OF PROJECTILE (CAL↑3):  194
AXIAL MOMENT OF INERTIA (CAL↑5):  23
TRANSVERSE MOMENT OF INERTIA (CAL↑5):  4975
1.0 CALIBER REFERENCE DIAMETER (IN.):  1.07



ENTER YES FOR MENU:
```

USER DEFINABLE KEY DEFINITIONS

1......NOMENCLATURE
2......TABLE OF AERODYNAMIC COEFFICIENTS
3......CNAT vs. MACH NUMBER PLOT
4......CDT vs. MACH NUMBER PLOT
5......VELOCITY vs. RANGE PLOT
6......CMAT,CG vs. MACH NUMBER PLOT
7......J ZETA vs. MACH NUMBER PLOT
8......LONG ROD FINNED PROJECTILE DESIGN
9......RETURN TO MENU

PLEASE PRESS USER DEFINABLE KEY TO CONTINUE

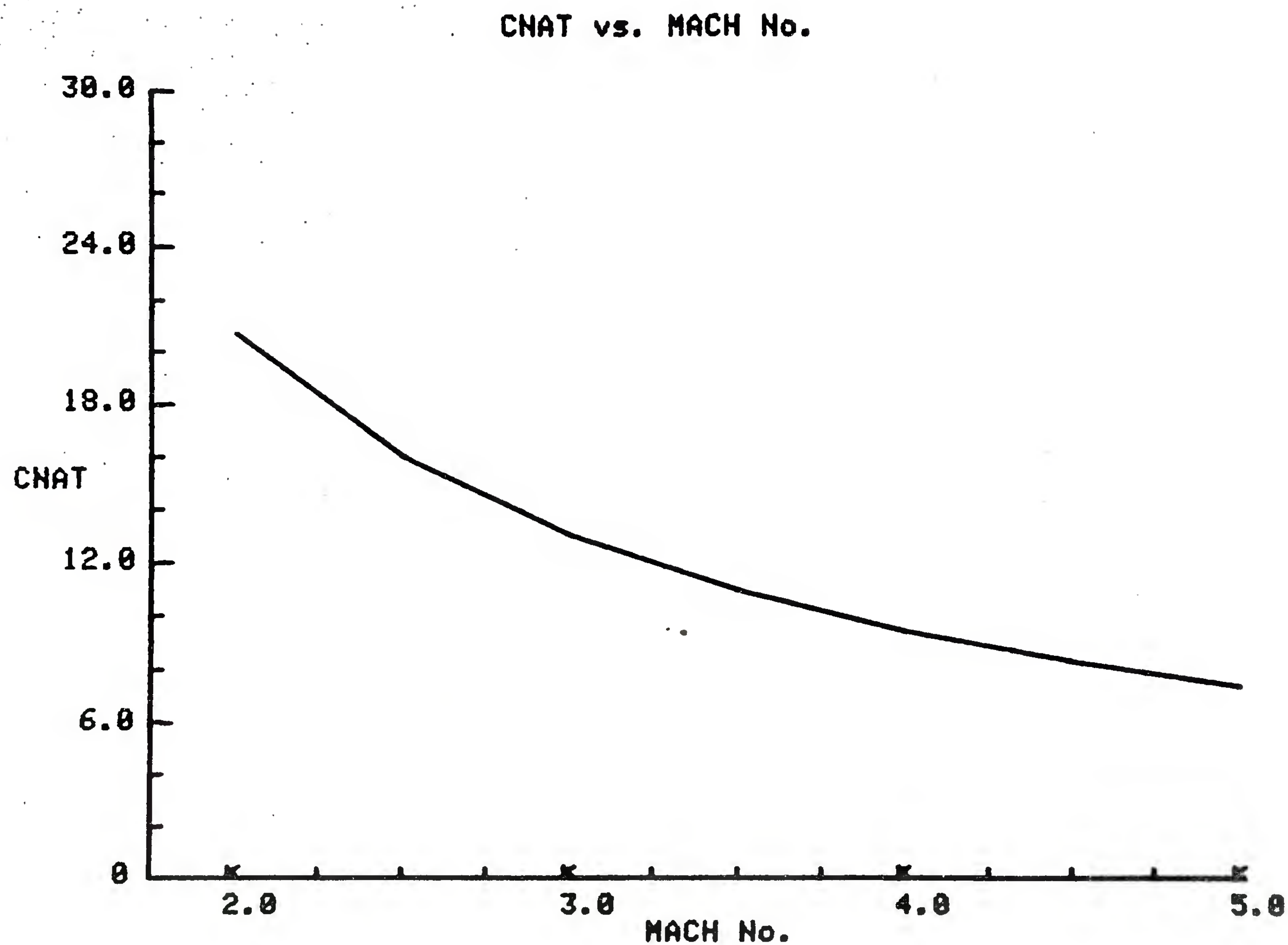
NOMENCLATURE

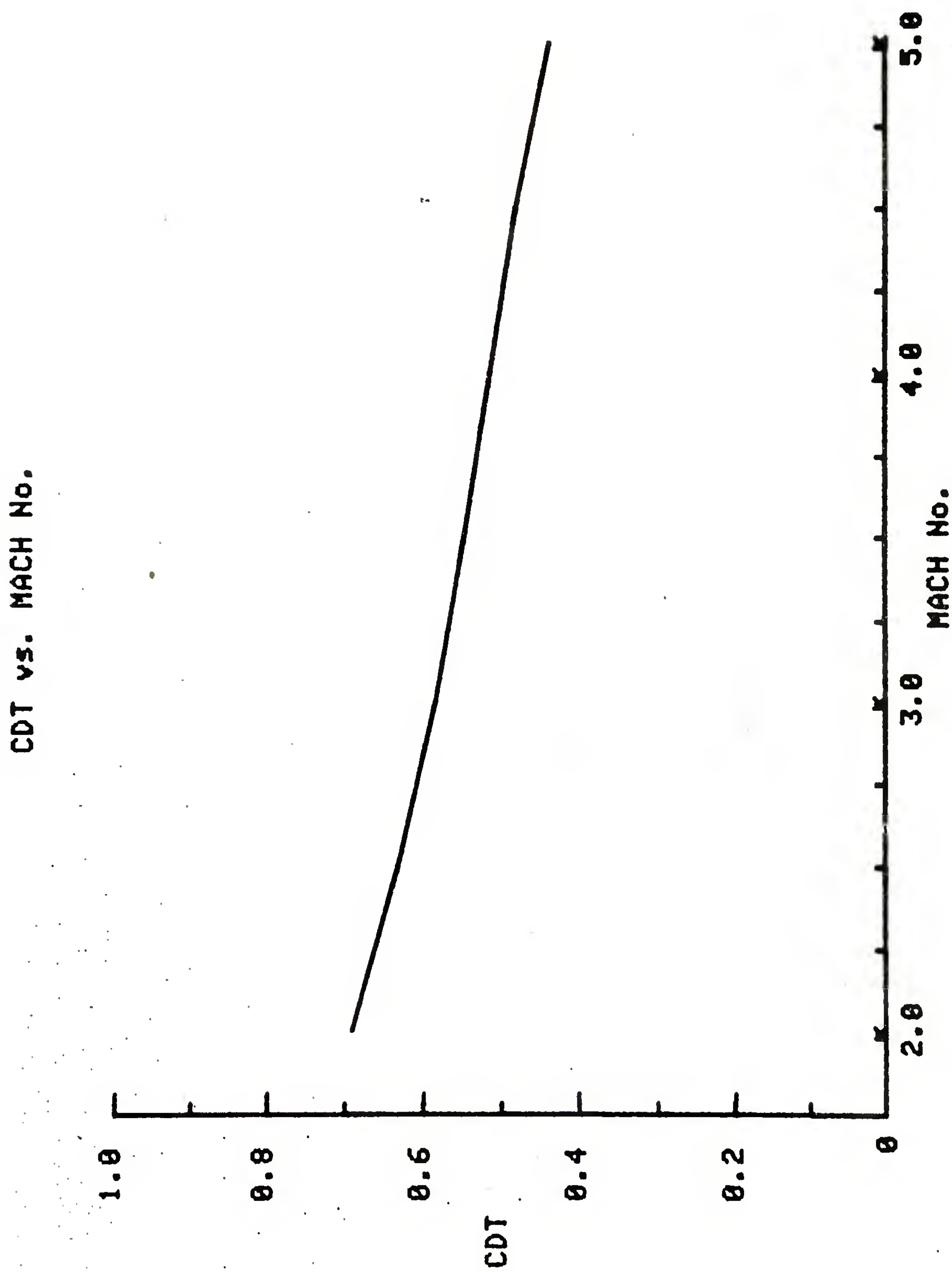
CNAB	Slope of the Normal Force Coefficient for the projectile body
XCPB	Pressure coefficient for the projectile body
CMAB	Slope of the Pitching Moment Coefficient for the projectile body
CNAF	Slope of the Normal Force Coefficient for the projectile fins
CNAT	Slope of the Total Normal Force Coefficient
CMAT	Slope of the Total Pitching Moment Coefficient
CG-CP	Center of gravity minus center of pressure
CMAT,CG	Slope of the Total Pitching Moment Coefficient about the center of gravity
CDWB	Coefficient of wave drag for the projectile body
CDBB	Base drag coefficient for the projectile body
CDVB	Viscous drag coefficient for the projectile body
CDGRV	Profile drag of grooved section of body
CDTB	Total drag coefficient for the projectile body
CDWF	Wave drag coefficient for the projectile fins
CDBF	Base drag coefficient for the projectile fins
CDVF	Viscous drag coefficient for the projectile fins
CDTF	Total drag coefficient for the projectile fins
CDT	Total drag coefficient
CLA	Slope of the Lift Coefficient
J ZETA	Aerodynamic jump factor

STATIC AERODYNAMIC COEFFICIENTS FOR LONG ROD FINNED PROJECTILES

MACH NUMBER

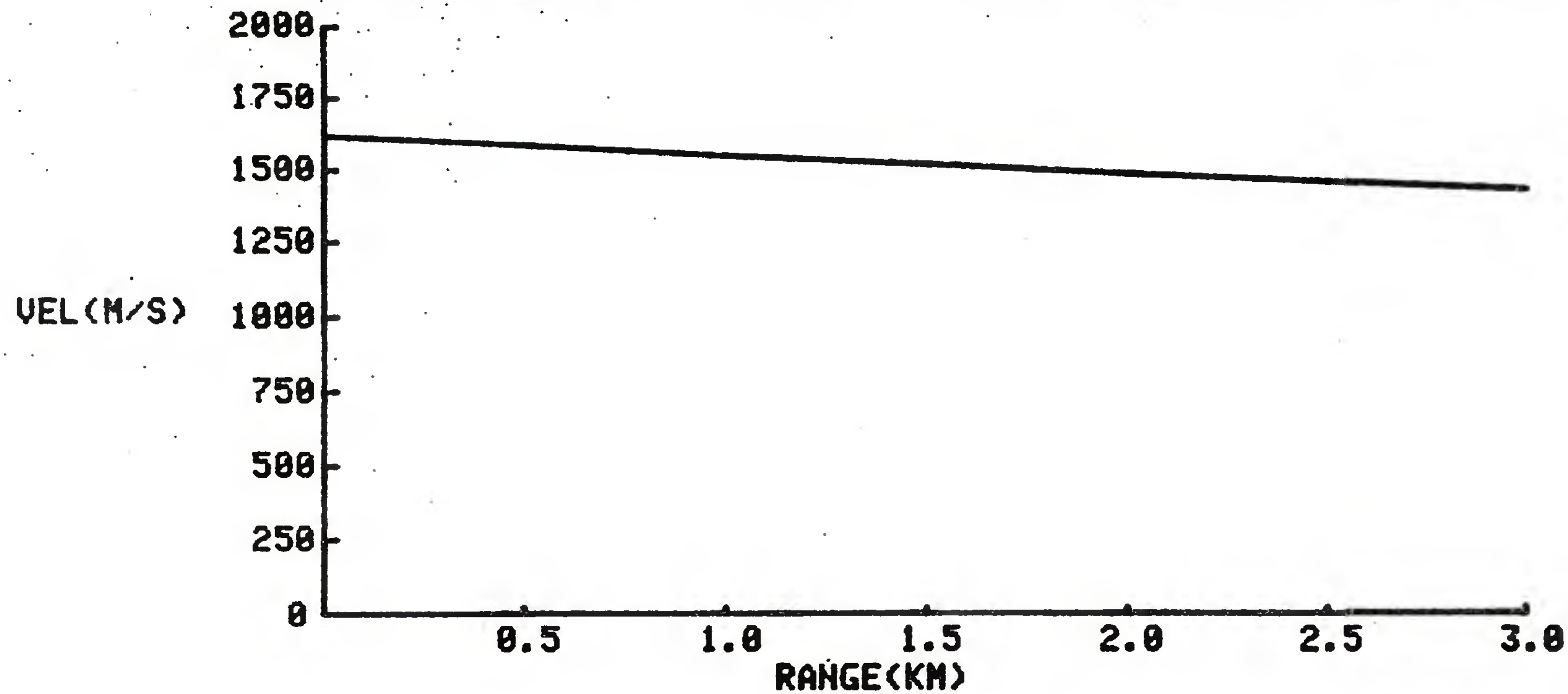
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
CNAB	1.494	1.299	1.185	1.110	1.057	1.018	0.988
XCPB	4.792	3.414	2.694	2.257	1.967	1.764	1.616
CMAB	7.157	4.434	3.193	2.506	2.080	1.796	1.597
CNAF	1.993	1.565	1.295	1.108	0.969	0.862	0.777
CNAT	20.736	15.998	13.028	10.966	9.444	8.269	7.334
CMAT	395.761	301.284	242.349	201.550	171.445	148.236	129.760
CG-CP	-7.225	-6.973	-6.743	-6.519	-6.294	-6.066	-5.832
CMAT,CG	-149.829	-111.547	-87.842	-71.489	-59.442	-50.161	-42.773
CDWB	0.057	0.053	0.051	0.049	0.047	0.045	0.044
CDBB	0.169	0.145	0.121	0.097	0.073	0.049	0.025
CDVB	0.339	0.305	0.270	0.235	0.201	0.166	0.131
CDGRV	0.017	0.036	0.065	0.102	0.144	0.185	0.215
CDTB	0.565	0.503	0.442	0.381	0.320	0.260	0.200
CDWF	0.007	0.005	0.004	0.004	0.003	0.003	0.003
CDBF	0.089	0.077	0.064	0.051	0.039	0.026	0.013
CDVF	0.011	0.010	0.009	0.008	0.007	0.006	0.004
CDTF	0.108	0.092	0.078	0.063	0.049	0.034	0.020
CDT	0.690	0.631	0.584	0.546	0.513	0.480	0.436
CLA	20.046	15.367	12.444	10.421	8.931	7.789	6.899
J ZETA	-3.431	-3.533	-3.633	-3.738	-3.853	-3.982	-4.136


CNAT vs. MACH No.
30.0
24.0
18.0
CNAT
12.0
6.0
0
2.0
3.0
4.0
5.0
MACH No.


CDT vs. MACH No.
CDT
1.0
0.8
0.6
0.4
0.2
0
2.0
3.0
4.0
5.0
MACH No.

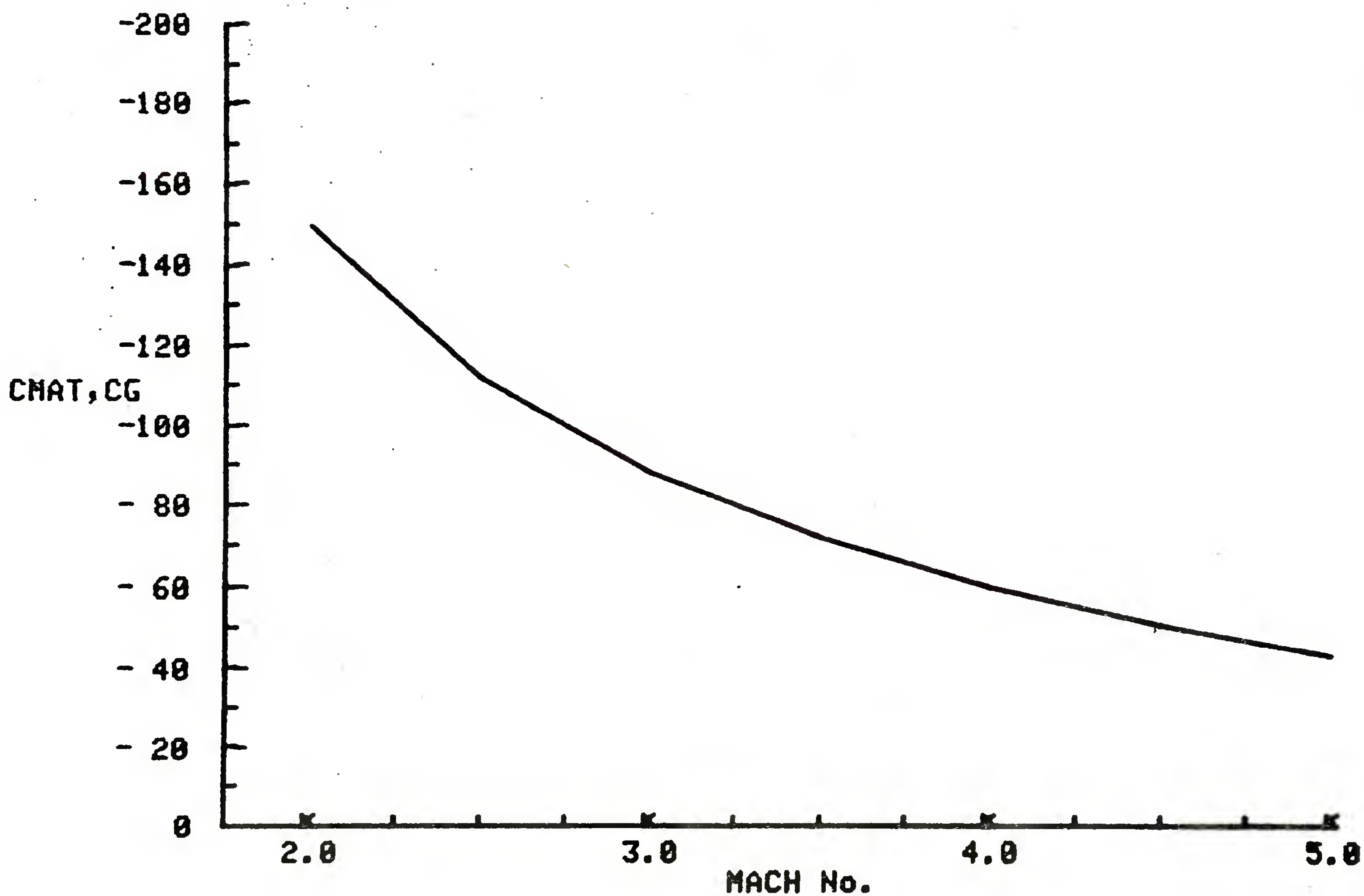
VELOCITY vs. RANGE

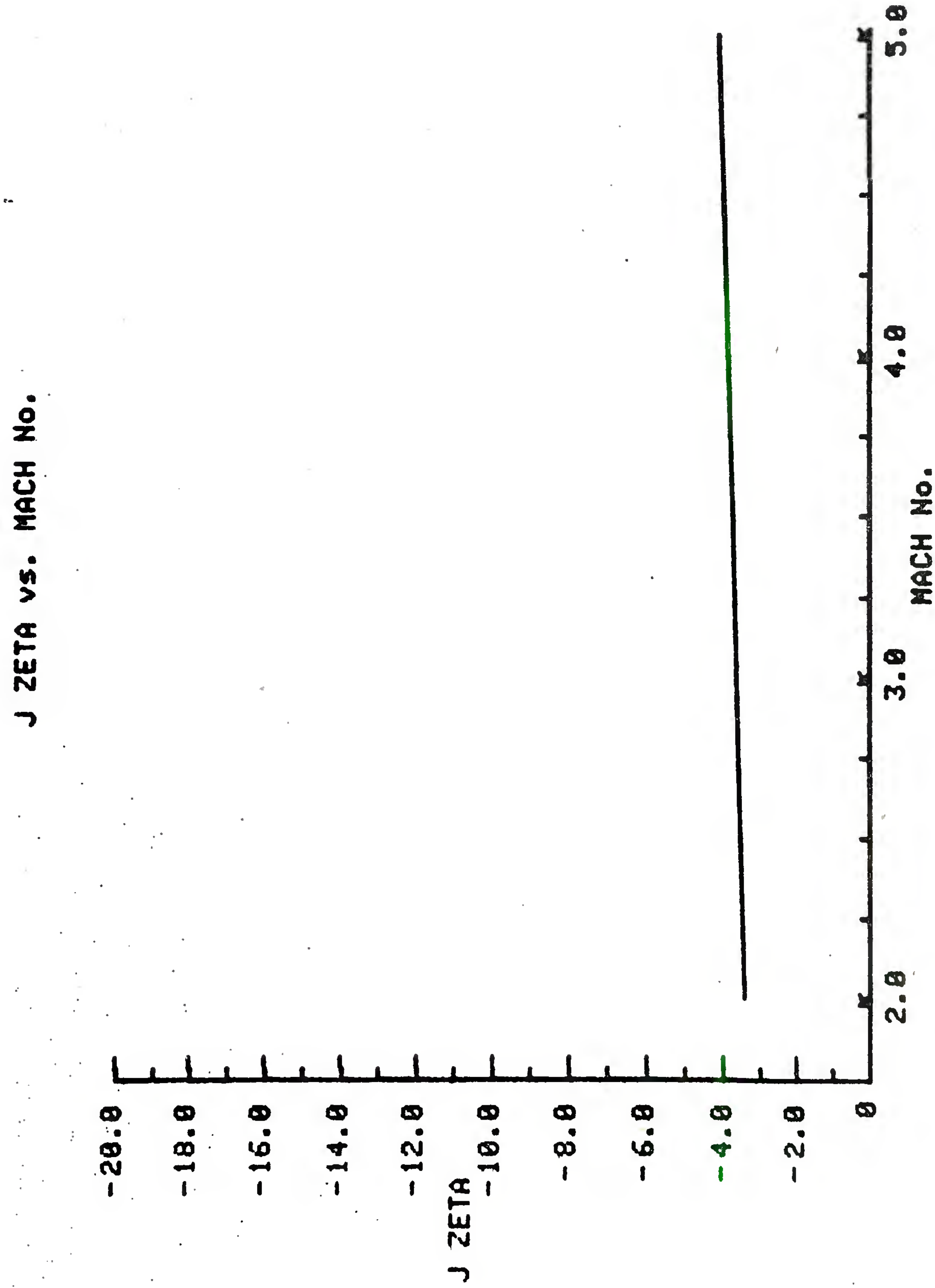
MUZZLE MACH No. 4.73 INITIAL YAW CYCLE 42.419M



RANGE	3000 M	RETARDATION	64.708 M/S/KM
RANGE	2500 M	RETARDATION	64.934 M/S/KM
RANGE	2000 M	RETARDATION	65.147 M/S/KM
RANGE	1500 M	RETARDATION	65.348 M/S/KM
RANGE	1000 M	RETARDATION	65.536 M/S/KM
RANGE	500 M	RETARDATION	65.711 M/S/KM
RANGE	0 M	RETARDATION	65.711 M/S/KM

CMAT,CG vs. MACH No.





J ZETA vs. MACH No.
J ZETA
-20.0
-18.0
-16.0
-14.0
-12.0
-10.0
-8.0
-6.0
-4.0
-2.0
0
MACH No.
2.0
3.0
4.0
5.0

APPENDIX C

PROGRAM LISTING

```
1 GO TO 100
4 GO TO 3950
8 GO TO 5670
12 GO TO 6070
16 GO TO 6690
20 GO TO 7240
24 GO TO 7850
28 GO TO 8540
32 GO TO 660
36 GO TO 3760
100 PAGE
110 DIM Q(20,7),Q1(7),A$(1),R2(20),R3(20),V(20)
120 PRI "THIS PROGRAM WILL CALCULATE AND PLOT ESTIMATED STATIC AERODYN";
130 PRINT "AMIC"
140 PRINT "  COEFFICIENTS OF LONG ROD FINNED PROJECTILES FOR 2<M<5"
150 PRINT
160 PRINT "INPUT NUMBER OF FINS (4 or 6): ";
170 INPUT N
180 PRINT
190 PRINT "INPUT THESE VALUES IN CALIBERS "
200 PRINT
210 PRINT "INPUT CONICAL NOSE LENGTH: ";
220 INPUT L
230 PRINT "INPUT CYLINDRICAL BODY LENGTH: ";
240 INPUT L1
250 PRINT "INPUT GROOVE LOCATION/NOSE: ";
260 INPUT P1
270 PRINT "INPUT GROOVE LENGTH: ";
280 INPUT P2
290 PRINT "INPUT FIN DIMENSION (BLADE HEIGHT): ";
300 INPUT H2
310 PRINT "INPUT FIN BLADE LENGTH AT ROOT: ";
320 INPUT C
330 PRINT "INPUT FIN DIMENSION (ROOT RECESS): ";
```

```
340 INPUT G
350 PRINT "INPUT FIN DIMENSION (BLADE EXTENSION FROM BODY): ";
360 INPUT K
370 PRINT "INPUT FIN DIMENSION (MAXIMUM THICKNESS): ";
380 INPUT T
390 PRINT "INPUT FIN BLADE LENGTH AT TIP: ";
400 INPUT C1
410 PRINT "INPUT CENTER OF GRAVITY OF PROJECTILE : ";
420 INPUT C2
430 PRINT "INPUT 1.0 CALIBER REFERENCE DIAMETER (MILLIMETERS): ";
440 INPUT D1
450 D=0
460 IF D1<>0 THEN 490
470 PRINT "INPUT 1.0 CALIBER REFERENCE DIAMETER (INCHES): ";
480 INPUT D
490 PRINT "INPUT NORMALIZED WEIGHT OF PROJECTILE (CAL↑3): ";
500 INPUT W
510 PRINT "INPUT AXIAL MOMENT OF INERTIA(CAL↑5): ";
520 INPUT I
530 PRINT "INPUT TRANSVERSE MOMENT OF INERTIA(CAL↑5): ";
540 INPUT I1
550 PRINT
560 PRINT "INPUT THESE RANGE VALUES"
570 PRINT
580 PRINT "INPUT MACH NUMBER AT MUZZLE: ";
590 INPUT M0
600 PRINT "INPUT MAXIMUM RANGE (METERS, <=4000): ";
610 INPUT S
620 S9=S
630 PRINT
640 PRINT "INPUT PLOTTING DEVISE NUMBER(1=PEN PLOTTER,32=SCREEN): ";
650 INPUT A
660 PAGE
670 SET DEGREES
680 B=20
```

```
690 B1=25
700 B2=L+L1+K-C
710 B3=L+L1
720 B4=B2+C+G-C1
730 B5=B4+C1
740 B6=B5-G
750 F=ATN((-B2+B5-C1)/H2)
760 F=INT(F*100)/100
770 Z=0
780 B7=H2+0.5+B
790 B8=-H2-0.5+B
800 B9=B1-(H2+0.5)*SIN(60)
810 E=B1+(H2+0.5)*SIN(60)
820 E1=B+(H2+0.5)*COS(60)
830 E2=B-(H2+0.5)*COS(60)
840 E3=B1+H2+0.5
850 E4=B1-H2-0.5
860 VIEWPORT 0,130,0,100
870 WINDOW -2,40,-2,26
880 MOVE @A:-1,20
890 DRAW @A:20,20
900 MOVE @A:0,B
910 DRAW @A:L,B+0.5
920 DRAW @A:L,B-0.5
930 DRAW @A:0,B
940 MOVE @A:L,B+0.5
950 DRAW @A:B3,B+0.5
960 DRAW @A:B3,B-0.5
970 DRAW @A:L,B-0.5
980 MOVE @A:B2,B+0.5
990 DRAW @A:B4,B7
1000 DRAW @A:B5,B7
1010 DRAW @A:B6,B+0.5
1020 DRAW @A:B6,B-0.5
1030 DRAW @A:B5,B8
```

```
1040 DRAW @A:B4,B8
1050 DRAW @A:B2,B-0.5
1060 IF N<>6 THEN 1110
1070 MOVE @A:B9+7,E1
1080 DRAW @A:E+7,E2
1090 MOVE @A:B9+7,E2
1100 DRAW @A:E+7,E1
1110 E5=H2+0.5
1120 E6=B+E5
1130 E7=B-E5
1140 MOVE @A:B1+7,E6
1150 DRAW @A:B1+7,E7
1160 IF N<>4 THEN 1210
1170 MOVE @A:B1+7,E6
1180 DRAW @A:B1+7,E7
1190 MOVE @A:E3+7,B
1200 DRAW @A:E4+7,B
1210 MOVE @A:B1+7,B+0.5
1220 DRAW @A:B1-0.5*SIN(22.5)+7,B+0.5*COS(22.5)
1230 DRAW @A:B1-0.5*COS(22.5)+7,B+0.5*SIN(22.5)
1240 DRAW @A:B1-0.5+7,B
1250 DRAW @A:B1-0.5*COS(22.5)+7,B-0.5*SIN(22.5)
1260 DRAW @A:B1-0.5*SIN(45)+7,B-0.5*COS(45)
1270 DRAW @A:B1-0.5*SIN(22.5)+7,B-0.5*COS(22.5)
1280 DRAW @A:B1+7,B-0.5
1290 DRAW @A:B1+0.5*SIN(45)+7,B-0.5*COS(45)
1300 DRAW @A:B1+0.5*COS(22.5)+7,B-0.5*SIN(22.5)
1310 DRAW @A:B1+0.5+7,B
1320 DRAW @A:B1+0.5*COS(22.5)+7,B+0.5*SIN(22.5)
1330 DRAW @A:B1+0.5*SIN(45)+7,B+0.5*SIN(45)
1340 DRAW @A:B1+0.5*SIN(22.5)+7,B+0.5*COS(22.5)
1350 DRAW @A:B1+7,B+0.5
1360 MOVE @A:0,B-0.2
1370 DRAW @A:0,B-5
1380 MOVE @A:L,B-0.7
```

```
1390 DRAW @A:L,B-2
1400 MOVE @A:B3,B-0.7
1410 DRAW @A:B3,B-1.1
1420 MOVE @A:B3,B-1.9
1430 DRAW @A:B3,B-4
1440 MOVE @A:B5,B8-0.2
1450 DRAW @A:B5,B-5
1460 MOVE @A:-0.25,B-1.5
1470 DRAW @A:L+0.5,B-1.5
1480 RMOVE @A:0.5,-0.5/2
1490 PRINT @A:L
1500 MOVE @A:0,B-3
1510 DRAW @A:3.5,B-3
1520 RMOVE @A:-0.2,-0.5/2
1530 PRINT @A:B3
1540 MOVE @A:7,B-3
1550 DRAW @A:B3,B-3
1560 MOVE @A:0,B-4.5
1570 DRAW @A:5.5,B-4.5
1580 RMOVE @A:-0.2,-0.5/2
1590 PRINT @A:B5
1600 MOVE @A:9,B-4.5
1610 DRAW @A:B5,B-4.5
1620 MOVE @A:0,B+0.2
1630 DRAW @A:0,B+5
1640 MOVE @A:C2,B+3
1650 DRAW @A:C2,B+5
1660 MOVE @A:0,B+4.5
1670 DRAW @A:1,B+4.5
1680 RMOVE @A:-0.2,-0.5/2
1690 PRINT @A:C2
1700 MOVE @A:0.5,2+B
1710 DRAW @A:0,2+B
1720 RMOVE 0.2,0.25
1730 IF P1=0 THEN 1790
```

```
1740 PRINT @A:P1
1750 MOVE @A:P1-1.2,2+B
1760 DRAW @A:P1+P2+0.2,2+B
1770 MOVE @A:P1+P2+0.5,2+B-0.25
1780 PRINT @A:P2
1790 MOVE @A:5,B+4.5
1800 DRAW @A:C2,B+4.5
1810 MOVE @A:C2-0.2,B-0.2
1820 DRAW @A:C2+0.1,B+0.12
1830 MOVE @A:C2+0.1,B-0.12
1840 DRAW @A:C2-0.2,B+0.2
1850 MOVE @A:P1,B+0.7
1860 DRAW @A:P1,B+2.5
1870 MOVE @A:P1+P2,B+0.7
1880 DRAW @A:P1+P2,B+2.5
1890 H=0.1*SQR(8)
1900 MOVE @A:C2+H,B
1910 FOR I5=1 TO 8
1920 Q5=I5*360/8
1930 X=H*COS(Q5)+C2
1940 Y=H*SIN(Q5)+B
1950 DRAW @A:X,Y
1960 NEXT I5
1970 MOVE @A:P1,0.5+B
1980 DRAW @A:P1+P2,-0.5+B
1990 DRAW @A:P1+P2,0.5+B
2000 DRAW @A:P1,-0.5+B
2010 DRAW @A:P1,0.5+B
2020 MOVE @A:B1-0.05+7,B7+0.2
2030 DRAW @A:B1-0.05+7,B7+2
2040 MOVE @A:B1+0.05+7,B7+0.2
2050 DRAW @A:B1+0.05+7,B7+2
2060 MOVE @A:B1-0.5+7,B7+1
2070 DRAW @A:B1+7.45,B7+1
2080 PRINT @A:T
```

```
2090 MOVE @A:B2+7,B-9.5
2100 DRAW @A:B4+7,B7-10
2110 DRAW @A:B5+7,B7-10
2120 DRAW @A:B6+7,B-9.5
2130 DRAW @A:B6+7,B-10
2140 DRAW @A:B3+7,B-10
2150 DRAW @A:B3+7,B-9.5
2160 DRAW @A:B2+7,B-9.5
2170 IF C1=0 THEN 2180
2180 MOVE @A:B4+7,B7-9.8
2190 DRAW @A:B4+7,B7-8.8
2200 MOVE @A:B5+7,B7-9.8
2210 DRAW @A:B5+7,B7-8.8
2220 MOVE @A:B4+6.5,B7-9.5
2230 DRAW @A:B4+7,B7-9.5
2240 MOVE @A:B5+7,B7-9.5
2250 DRAW @A:B5+8,B7-9.5
2260 MOVE @A:B5+8.2,B7-9.6
2270 RMOVE @A:0,-0.25
2280 PRINT @A:C1
2290 IF G=0 THEN 2400
2300 MOVE @A:B5+7,B7-10.2
2310 DRAW @A:B5+7,B7-14
2320 MOVE @A:B6+7,B-10.2
2330 DRAW @A:B6+7,B-10.7
2340 MOVE @A:B6+6.5,B-10.5
2350 DRAW @A:B6+7,B-10.5
2360 MOVE @A:B5+7,B-10.5
2370 DRAW @A:B5+8,B-10.5
2380 MOVE @A:B5+8.2,B-10.6
2390 PRINT @A:G
2400 IF K=0 THEN 2500
2410 MOVE @A:B3+7,B-10.2
2420 DRAW @A:B3+7,B-10.7
2430 MOVE @A:B3+7,B-10.5
```

```
2440 DRAW @A:B6+7,B-10.5
2450 MOVE @A:(B3+B6)/2+7,B-10.7
2460 DRAW @A:B3+7,B-13.5
2470 DRAW @A:B3+7.5,B-13.5
2480 RMOVE @A:0.1,-0.25
2490 PRINT @A:K
2500 MOVE @A:B2+7,B-9.7
2510 DRAW @A:B2+7,B-12
2520 MOVE @A:B2+7,B-11.7
2530 DRAW @A:B2+6.7,B-11.7
2540 MOVE @A:B5+7,B-10
2550 DRAW @A:B5+7,B-12
2560 MOVE @A:B5+7,B-11.7
2570 DRAW @A:B5+7.3,B-11.7
2580 RMOVE @A:0,-0.5
2590 PRINT @A:C+G
2600 MOVE @A:B2+7,B-9.8
2610 DRAW @A:B2+7,B-9
2620 MOVE @A:B2+7+0.2*(B4-B2),B-9.5+0.4*H2
2630 MOVE @A:B2+7+0.2*(B4-B2),B-9.5+0.4*H2
2640 DRAW @A:(B2+B4)/2+7,B7-7.5
2650 RDRAW @A:0.5,0
2660 RMOVE @A:0.2,-0.25
2670 PRINT @A:F
2680 MOVE @A:B5+1,B7
2690 DRAW @A:B5+1,B8-1
2700 DRAW @A:B5+2,B8-1
2710 MOVE @A:B5+2.2,B8-1.1
2720 RMOVE @A:0,-0.25
2730 PRINT @A:2*H2+1
2740 MOVE @A:B5+0.2,B7
2750 DRAW @A:B5+1.5,B7
2760 MOVE @A:B5+0.2,B8
2770 DRAW @A:B5+1.5,B8
2780 MOVE @A:B5+7.2,B7-10
```

```
2790 DRAW @A:B5+8.5,B7-10
2800 MOVE @A:B5+7.8,B7-10
2810 DRAW @A:B5+7.8,B-9.5
2820 MOVE @A:B5+0.2,B7
2830 DRAW @A:B5+1.5,B7
2840 MOVE @A:B5+0.2,B8
2850 DRAW @A:B5+1.5,B8
2860 MOVE @A:B5+8.1,B-9.5+H2/2
2870 RDRAW @A:4,0
2880 MOVE @A:B5+7.2,B-9.5
2890 DRAW @A:B5+8.5,B-9.5
2900 MOVE @A:B5+12.5,B-9.5+H2/2
2910 PRINT @A:H2
2920 MOVE @A:1.5,B-9
2930 PRINT @A:"WT =  ";
2940 PRINT @A:W;
2950 PRINT @A:" WCAL3"
2960 MOVE @A:1.5,B-10
2970 PRINT @A:"IX =  ";
2980 PRINT @A:I;
2990 PRINT @A:" ICAL5"
3000 MOVE @A:1.5,B-11
3010 PRINT @A:"IY =  ";
3020 PRINT @A:I1;
3030 PRINT @A:" ICAL5"
3040 MOVE @A:1.5,B-12
3050 PRINT @A:"DIA=  ";
3060 IF D=0 THEN 3100
3070 PRINT @A:D;
3080 PRINT @A:"IN/CAL "
3090 GO TO 3120
3100 PRINT @A:D1;
3110 PRINT @A:" MM/CAL "
3120 HOME @A:
3130 PRINT @A: USING 3140:"LONG ROD FINNED PROJECTILE DESIGN"
```

```
3140 IMAGE20X,33A
3150 PRINT @A:"JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ "
3160 PRINT "G"
3170 PRINT "IF YOU WANT THE INITIAL DATA PRINTED OUT ENTER 'YES': ";
3180 INPUT A$
3190 IF A$="Y" THEN 3210
3200 GO TO 3680
3210 PAGE
3220 PRINT "ALL VALUES ARE IN CALIBERS UNLESS OTHERWISE NOTED"
3230 PRINT
3240 PRINT "CONICAL NOSE LENGTH: ";
3250 PRINT L
3260 PRINT "CYLINDRICAL BODY LENGTH: ";
3270 PRINT L1
3280 PRINT "GROOVE LOCATION/NOSE: ";
3290 PRINT P1
3300 PRINT "GROOVE LENGTH: ";
3310 PRINT P2
3320 PRINT "FIN DIMENSION (BLADE HEIGHT): ";
3330 PRINT H2
3340 PRINT "FIN BLADE LENGTH AT ROOT: ";
3350 PRINT C
3360 PRINT "FIN DIMENSION (ROOT RECESS): ";
3370 PRINT G
3380 PRINT "FIN DIMENSION (BLADE EXTENSION FROM BODY): ";
3390 PRINT K
3400 PRINT "FIN DIMENSION (MAXIMUM THICKNESS): ";
3410 PRINT T
3420 PRINT "FIN SWEEP ANGLE (DEGREES): ";
3430 PRINT F
3440 PRINT "FIN BLADE LENGTH AT TIP: ";
3450 PRINT C1
3460 PRINT "NUMBER OF BLADES: ";
3470 PRINT N
3480 PRINT "CENTER OF GRAVITY: ";
```

```
3490 PRINT C2
3500 PRINT "MACH NUMBER AT MUZZLE: ";
3510 PRINT M0
3520 PRINT "MAXIMUM RANGE (METERS): ";
3530 PRINT S
3540 PRINT "WEIGHT OF PROJECTILE (CAL↑3): ";
3550 PRINT W
3560 PRINT "AXIAL MOMENT OF INERTIA (CAL↑5): ";
3570 PRINT I
3580 PRINT "TRANSVERSE MOMENT OF INERTIA (CAL↑5): ";
3590 PRINT I1
3600 IF D=0 THEN 3640
3610 PRINT "1.0 CALIBER REFERENCE DIAMETER (IN.): ";
3620 PRINT D
3630 GO TO 3660
3640 PRINT "1.0 CALIBER REFERENCE DIAMETER (MM): ";
3650 PRINT D1
3660 PRINT "G"
3670 PRINT "JJJJJJJ  "
3680 PRINT "ENTER YES FOR MENU: ";
3690 INPUT A$
3700 IF A$="Y" THEN 3720
3710 END
3720 PAGE
3730 PRINT "WAIT"
3740 S=S9
3750 GOSUB 4280
3760 PAGE
3770 PRINT "                              USER DEFINABLE KEY DEFINITIONS"
3780 PRINT
3790 PRINT
3800 PRINT
3810 PRINT "1......NOMENCLATURE"
3820 PRINT "2......TABLE OF AERODYNAMIC COEFFICIENTS"
3830 PRINT "3......CHAT vs. MACH NUMBER PLOT"
```

```
3840 PRINT "4......CDT vs. MACH NUMBER PLOT"
3850 PRINT "5......VELOCITY vs. RANGE PLOT"
3860 PRINT "6......CMAT,CG vs. MACH NUMBER PLOT"
3870 PRINT "7......J ZETA vs. MACH NUMBER PLOT"
3880 PRINT "8......LONG ROD FINNED PROJECTILE DESIGN"
3890 PRINT "9......RETURN TO MENU"
3900 PRINT
3910 PRINT
3920 PRINT "PLEASE PRESS USER DEFINABLE KEY TO CONTINUE"
3930 PRINT "G"
3940 END
3950 REM
3960 REM THIS IS THE NOMENCLATURE
3970 REM
3980 PAGE
3990 PRINT "                              NOMENCLATURE"
4000 PRINT "JJJ"
4010 PRINT "CNAB    Slope of the Normal Force Coefficient for the proj";
4020 PRINT "ectile body"
4030 PRINT "XCPB    Pressure coefficient for the projectile body"
4040 PRINT "CMAB    Slope of the Pitching Moment Coefficient for ";
4050 PRINT "the projectile body"
4060 PRINT "CNAF    Slope of the Normal Force Coefficient for the";
4070 PRINT " projectile fins"
4080 PRINT "CNAT    Slope of the Total Normal Force Coefficient"
4090 PRINT "CMAT    Slope of the Total Pitching Moment Coefficient"
4100 PRINT "CG-CP   Center of gravity minus center of pressure"
4110 PRINT "CMAT,CG Slope of the Total Pitching Moment Coefficient";
4120 PRINT " about the center"
4130 PRINT "        of gravity"
4140 PRINT "CDWB    Coefficient of wave drag for the projectile body"
4150 PRINT "CDBB    Base drag coefficient for the projectile body"
4160 PRINT "CDVB    Viscous drag coefficient for the projectile body"
4170 PRINT "CDGRV   Profile drag of grooved section of body"
4180 PRINT "CDTB    Total drag coefficient for the projectile body"
```

```
4190 PRINT "CDWF    Wave drag coefficient for the projectile fins"
4200 PRINT "CDBF    Base drag coefficient for the projectile fins"
4210 PRINT "CDVF    Viscous drag coefficient for the projectile fins"
4220 PRINT "CDTF    Total drag coefficient for the projectile fins"
4230 PRINT "CDT     Total drag coefficient"
4240 PRINT "CLA     Slope of the Lift Coefficient"
4250 PRINT "J ZETA  Aerodynamic jump factor"
4260 PRINT "G"
4270 END
4280 REM
4290 REM SUBROUTINE TO DO CALCULATIONS
4300 REM
4310 G6=L+L1
4320 J2=H2*C+H2*C1+K-G
4330 J3=H2*H2*4/J2
4340 M=2
4350 FOR Y=1 TO 7
4360 G3=SQR(M*M-1)
4370 G4=G3/L
4380 G5=L1/G3
4390 Q1(Y)=M
4400 G7=(1.9+1.3*G4+0.0149*G5)*(1/G3↑0.7)*(2.3-0.0675*G6)
4410 G8=TAN(F)/G3
4420 G9=(0.69+0.65*G4+0.5*G5)*(1/G3↑0.46)
4430 J1=G7*G9
4440 Q(1,Y)=G7
4450 Q(2,Y)=G9
4460 Q(3,Y)=J1
4470 J4=((1.25*LOG(J3)*0.25*TAN(F)+0.9*T/C)*G8+4)/G3
4480 J5=1/G3↑0.58*0.54/M*(1-1/G8)*(0.6*J3-1)/TAN(F)
4490 IF G8>2 THEN 4510
4500 J6=J4
4510 IF G8<=2 THEN 4530
4520 J6=J4+J5
4530 Q(4,Y)=J6
```

```
4540 J7=J2*J6*N/PI
4550 J8=(G6+K-G-C/2)*J7
4560 J9=1/(1+2*H2)
4570 J9=2.72↑J9
4580 J=1.34-0.17*G3/TAN(F)
4590 J9=J9*J
4600 J=J9*9/L1*J7+G7
4610 K1=J
4620 K2=J9*9/L1*J8+J1
4630 K3=K2/J
4640 K4=C2-K3
4650 K5=K4*J
4660 K6=K5
4670 Q(5,Y)=J
4680 Q(6,Y)=K2
4690 Q(7,Y)=K4
4700 Q(8,Y)=K5
4710 J=6+J/10
4720 K5=6+K5*6/220
4730 K7=M*2-3.5
4740 K8=J
4750 K9=K7
4760 T1=K5
4770 T2=PI*(SQR(0.61685+2.4674*L*L)+L1)
4780 T3=J2/2
4790 T4=T*H2*N
4800 T5=M↑0.28*L↑1.73
4810 T5=0.7/T5
4820 T6=0.265-0.048*M
4830 T7=T2*(0.006333-9.18E-4*M)
4840 T8=H2/COS(F)
4850 T8=T*T/T8/T8
4860 T9=H*T8*T3*4/G3/PI
4870 T8=4*T4*T6/PI
4880 F1=0.869565*T3*T7/T2
```

```
4890 F2=T5+T6+T7
4900 F3=T8+T9+F1
4910 P4=M↑3.9/4000*F2*P2
4920 F4=F2+F3+P4
4930 F5=F4
4940 Q(9,Y)=T5
4950 Q(10,Y)=T6
4960 Q(11,Y)=T7
4970 Q(12,Y)=P4
4980 Q(13,Y)=F2
4990 Q(14,Y)=T9
5000 Q(15,Y)=T8
5010 Q(16,Y)=F1
5020 Q(17,Y)=F3
5030 Q(18,Y)=F4
5040 IF M<>3 THEN 5060
5050 F6=F4
5060 F4=F4*5+6
5070 IF M<>5 THEN 5090
5080 F7=(F4-6)/5
5090 F8=M*2+4
5100 F9=K1-F5
5110 Q(19,Y)=F9
5120 N1=I1/W*(F9/K6)
5130 Q(20,Y)=N1
5140 M=M+0.5
5150 N1=6+N1/2
5160 N2=N1
5170 O2=F8
5180 O3=F4
5190 NEXT Y
5200 N5=500
5210 Y=1
5220 N3=(F7-F6)/2
5230 N4=F6-3*N3
```

```
5240 N6=PI*0.075/62.4/8*N4/W
5250 N7=N3+N4/M0
5260 IF D<=0 THEN 5280
5270 N8=EXP(S*N6*39.37/D)
5280 IF D1<=0 THEN 5300
5290 N8=EXP(S*N6*1000/D1)
5300 N9=N4/(N7*N8-N3)
5310 N0=(M0-N9)*341380
5320 V(Y)=N9*341.38
5330 N0=N0/S
5340 R2(Y)=S
5350 R3(Y)=N0
5360 O4=0
5370 IF N9<>O4 THEN 5380
5380 O4=N9
5390 O5=S
5400 S=S-N5
5410 Y=Y+1
5420 IF S=0 THEN 5440
5430 GO TO 5260
5440 N3=(F7-F6)/2
5450 Y1=Y
5460 R2(Y)=0
5470 R3(Y)=R3(Y-1)
5480 V(Y)=M0*341.38
5490 N4=F6-3*N3
5500 N6=PI*0.075/62.4/8*N4/W
5510 N7=N3+N4/M0
5520 IF D<=0 THEN 5540
5530 N8=EXP(O5*N6*1000/D)
5540 IF D1<=0 THEN 5560
5550 N8=EXP(O5*N6*1000/D1)
5560 N9=N4/(N7*N8-N3)
5570 N0=(M0-N9)*341380
5580 N0=N0/O5
```

```
5590 O6=I1/K6*8*PI/0.0012
5600 O6=O6*O6
5610 O6=O6↑0.25
5620 IF D<=0 THEN 5640
5630 O1=O6*D/39.37
5640 IF D1<=0 THEN 5660
5650 O1=O6*D1/1000
5660 RETURN
5670 REM
5680 REM THIS IS THE TABLE OF CALCULATIONS
5690 REM
5700 PAGE
5710 PRINT "    STATIC AERODYNAMIC COEFFICIENTS FOR LONG ROD FINNED";
5720 PRINT " PROJECTILES"
5730 PRINT
5740 PRINT USING 5750:"MACH NUMBER"
5750 IMAGE 30X,11A
5760 PRINT
5770 PRINT USING 5780:"2.0","2.5","3.0","3.5","4.0","4.5","5.0"
5780 IMAGE12X,3A,6X,3A,7X,3A,7X,4(3A,6X)
5790 PRINT "CNAB"
5800 PRINT "XCPB"
5810 PRINT "CMAB"
5820 PRINT "CNAF"
5830 PRINT "CNAT"
5840 PRINT "CMAT"
5850 PRINT "CG-CP"
5860 PRINT "CMAT,CG"
5870 PRINT "CDWB"
5880 PRINT "CDBB"
5890 PRINT "CDVB"
5900 PRINT "CDGRV"
5910 PRINT "CDTB"
5920 PRINT "CDWF"
5930 PRINT "CDBF"
```

```
5940 PRINT "CDVF"
5950 PRINT "CDTF"
5960 PRINT "CDT"
5970 PRINT "CLA"
5980 PRINT "J ZETA"
5990 HOME
6000 PRINT "JJJJJ"
6010 FOR Y=1 TO 20
6020 PRINT USING 6030:Q(Y,1),Q(Y,2),Q(Y,3),Q(Y,4),Q(Y,5),Q(Y,6),Q(Y,7)
6030 IMAGE 8X,2(4D.3D,1X),2(1X,4D.3D,1X),2(4D.3D,1X),4D.3D
6040 NEXT Y
6050 PRINT "G"
6060 END
6070 PAGE
6080 REM
6090 REM THE GRAPH OF CNAT vs MACH NUMBER
6100 REM
6110 VIEWPORT 20,125,12,90
6120 WINDOW 1.75,5,0,30
6130 AXIS @A:0.25,2
6140 MOVE @A:2,0
6150 RMOVE @A:-0.02,-1.5
6160 PRINT @A:"2.0"
6170 FOR R1=3 TO 5
6180 RMOVE @A:1,0
6190 PRINT @A: USING 6200:R1
6200 IMAGE 1D.1D
6210 NEXT R1
6220 MOVE @A:1.75,0
6230 RMOVE @A:-0.1,-0.3
6240 PRINT @A:"0"
6250 MOVE @A:1.75,6
6260 RMOVE @A:-0.2,-0.33
6270 PRINT @A:"6.0"
6280 RMOVE @A:-0.056,0
```

```
6290 FOR R1=12 TO 30 STEP 6
6300 RMOVE @A:0,6
6310 PRINT @A: USING 6320:R1
6320 IMAGE 2D.1D
6330 NEXT R1
6340 MOVE @A:2,0
6350 RMOVE @A:-0.017,0
6360 PRINT @A:"|"
6370 FOR R1=3 TO 5
6380 RMOVE @A:1,0
6390 PRINT @A:"|"
6400 NEXT R1
6410 MOVE @A:2,6
6420 IF A=32 THEN 6450
6430 RMOVE @A:-0.22,-0.27
6440 GO TO 6460
6450 RMOVE @A:-0.22,-0.47
6460 PRINT @A:"-"
6470 FOR R1=12 TO 30 STEP 6
6480 RMOVE @A:0,6
6490 PRINT @A:"-"
6500 NEXT R1
6510 HOME @A:
6520 PRINT
6530 PRINT @A: USING 6540:"CNAT vs. MACH No."
6540 IMAGE 30X,17A
6550 PRINT @A:"JJJJJJJJJJJJJJ"
6560 PRINT @A: USING 6570:"CNAT"
6570 IMAGE 4X,4A
6580 PRINT @A:"JJJJJJJJJJJJJJ"
6590 PRINT @A: USING 6600:"MACH No."
6600 IMAGE 38X,8A
6610 MOVE @A:Q1(1),Q(5,1)
6620 FOR R1=2 TO 7
6630 DRAW @A:Q1(R1),Q(5,R1)
```

```
6640 NEXT R1
6650 PRINT "G"
6660 END
6670 REM THIS IS THE GRAPH OF CDT vs. MACH No.
6680 REM
6690 PAGE
6700 VIEWPORT 20,125,12,90
6710 WINDOW 1.75,5,0,1
6720 AXIS @A:0.25,0.1
6730 MOVE @A:2,0
6740 RMOVE @A:-0.06,-0.05
6750 PRINT @A:"2.0"
6760 FOR R1=3 TO 5
6770 RMOVE @A:1,0
6780 PRINT @A: USING 6790:R1
6790 IMAGE1D.1D
6800 NEXT R1
6810 MOVE @A:1.75,0
6820 RMOVE @A:-0.1,-0.015
6830 PRINT @A:"0"
6840 MOVE @A:1.75,0.2
6850 RMOVE @A:-0.25,-0.01
6860 PRINT @A:"0.2"
6870 FOR R1=0.4 TO 1 STEP 0.2
6880 RMOVE @A:0,0.2
6890 PRINT @A: USING 6900:R1
6900 IMAGE1D.1D
6910 NEXT R1
6920 HOME @A:
6930 PRINT @A: USING 6940:"CDT vs. MACH No."
6940 IMAGE31X,16A
6950 PRINT @A:"JJJJJJJJJJJJJJJ"
6960 PRINT @A: USING 6970:"CDT"
6970 IMAGE 3X,3A
6980 PRINT @A:"JJJJJJJJJJJJJJ"
```

```
6990 PRINT @A: USING 7000:"MACH No."
7000 IMAGE38X,8A
7010 MOVE @A:2,0
7020 RMOVE @A:-0.018,0
7030 PRINT @A:"|"
7040 FOR R1=3 TO 5
7050 RMOVE @A:1,0
7060 PRINT @A:"|"
7070 NEXT R1
7080 MOVE @A:1.75,0.2
7090 IF A=32 THEN 7120
7100 RMOVE @A:0.03,-0.01
7110 GO TO 7130
7120 RMOVE @A:0.03,-0.016
7130 PRINT @A:"-"
7140 FOR R1=0.4 TO 1 STEP 0.2
7150 RMOVE @A:0,0.2
7160 PRINT @A:"-"
7170 NEXT R1
7180 MOVE @A:Q1(1),Q(18,1)
7190 FOR R1=2 TO 7
7200 DRAW @A:Q1(R1),Q(18,R1)
7210 NEXT R1
7220 PRINT "G"
7230 END
7240 REM
7250 REM THIS IS THE GRAPH OF VELOCITY vs. RANGE
7260 REM
7270 PAGE
7280 S=S9
7290 S8=S9/1000
7300 VIEWPORT 25,125,40,90
7310 WINDOW 0,S8,0,2000
7320 AXIS @A:0.5,250
7330 MOVE @A:0.5,0
```

```
7340 RMOVE @A:-0.06,-135
7350 PRINT @A:"0.5"
7360 FOR R1=1 TO S8 STEP 0.5
7370 RMOVE @A:0.5,0
7380 PRINT @A: USING 7390:R1
7390 IMAGE1D.1D
7400 NEXT R1
7410 MOVE @A:0,0
7420 RMOVE @A:-0.08,-50
7430 PRINT @A:"0"
7440 MOVE @A:0,250
7450 RMOVE @A:-0.3*S8/4,-40
7460 PRINT @A:" 250"
7470 FOR R1=500 TO 2000 STEP 250
7480 RMOVE @A:0,250
7490 PRINT @A: USING 7500:R1
7500 IMAGE4D
7510 NEXT R1
7520 HOME @A:
7530 PRINT @A: USING 7540:"VELOCITY vs. RANGE"
7540 IMAGE 30X,18A
7550 PRINT @A:
7560 PRINT @A: USING 7570:M0,O1
7570 IMAGE15X,"MUZZLE MACH No. ",4D.2D,5X,"INITIAL YAW CYCLE ",4D.3D,"M"
7580 PRINT @A:"JJJJJJJ"
7590 PRINT @A:"VEL(M/S)"
7600 PRINT @A:"JJJJJJJJ  "
7610 PRINT @A: USING 7620:"RANGE(KM)"
7620 IMAGE 35X,9A
7630 PRINT @A:
7640 FOR Y=1 TO Y1
7650 PRINT @A: USING 7660:R2(Y),R3(Y)
7660 IMAGE14X,"RANGE",5D," M",15X,"RETARDATION",7D.3D," M/S/KM"
7670 NEXT Y
7680 FOR Y=1 TO Y1
```

```
7690 R2(Y)=R2(Y)/1000
7700 NEXT Y
7710 MOVE @A:R2(1),V(1)
7720 FOR R1=2 TO Y1
7730 DRAW @A:R2(R1),V(R1)
7740 NEXT R1
7750 DRAW @A:0,M0*340.29
7760 PRINT "G"
7770 FOR Y=1 TO Y1
7780 R2(Y)=R2(Y)*1000
7790 NEXT Y
7800 PRINT "G"
7810 END
7820 REM
7830 REM THIS IS THE GRAPH OF CMAT,CG vs. MACH No.
7840 REM
7850 PAGE
7860 VIEWPORT 20,125,12,90
7870 WINDOW 1.75,5,0,200
7880 AXIS @A:0.25,10
7890 MOVE @A:2,0
7900 RMOVE @A:-0.07,-9.5
7910 PRINT @A:"2.0"
7920 FOR R1=3 TO 5
7930 RMOVE @A:1,0
7940 PRINT @A: USING 7950:R1
7950 IMAGE 1D.1D
7960 NEXT R1
7970 MOVE @A:1.75,0
7980 RMOVE @A:-0.13,-3
7990 PRINT @A:"0"
8000 MOVE @A:1.75,20
8010 RMOVE @A:-0.2,-3.3
8020 PRINT @A:"20"
8030 FOR R1=40 TO 90 STEP 20
```

```
8040 RMOVE @A:0,20
8050 PRINT @A: USING 8060:R1
8060 IMAGE 2D
8070 NEXT R1
8080 MOVE @A:1.75,100
8090 RMOVE @A:-0.256,-3.3
8100 PRINT @A:"100"
8110 FOR R1=120 TO 200 STEP 20
8120 RMOVE @A:0,20
8130 PRINT @A: USING 8140:R1
8140 IMAGE3D
8150 NEXT R1
8160 HOME @A:
8170 PRINT @A: USING 8180:"CMAT,CG vs. MACH No."
8180 IMAGE29X,20A
8190 PRINT @A:"JJJJJJJJJJJJJJ"
8200 PRINT @A:"CMAT,CG"
8210 PRINT @A:"JJJJJJJJJJJJJJJ"
8220 PRINT @A: USING 8230:"MACH No."
8230 IMAGE38X,8A
8240 MOVE @A:2,0
8250 RMOVE @A:-0.017,0
8260 PRINT @A:"|"
8270 FOR R1=3 TO 5
8280 RMOVE @A:1,0
8290 PRINT @A:"|"
8300 NEXT R1
8310 MOVE @A:1.75,20
8320 IF A=32 THEN 8350
8330 RMOVE @A:0.03,-2
8340 GO TO 8360
8350 RMOVE @A:0.03,-2.95
8360 PRINT @A:"-"
8370 FOR R1=40 TO 200 STEP 20
8380 RMOVE @A:0,20
```

```
8390 PRINT @A:"-"
8400 NEXT R1
8410 MOVE @A:1.75,20
8420 RMOVE @A:-0.3,-2.95
8430 PRINT @A:"-"
8440 FOR R1=20 TO 180 STEP 20
8450 RMOVE @A:0,20
8460 PRINT @A:"-"
8470 NEXT R1
8480 MOVE @A:ABS(Q1(1)),ABS(Q(8,1))
8490 FOR R1=2 TO 7
8500 DRAW @A:ABS(Q1(R1)),ABS(Q(8,R1))
8510 NEXT R1
8520 PRINT "G"
8530 END
8540 REM
8550 REM THIS IS THE GRAPH OF J ZETA vs. MACH No.
8560 REM
8570 PAGE
8580 VIEWPORT 20,125,12,90
8590 WINDOW 1.75,5,0,20
8600 AXIS @A:0.25,1
8610 MOVE @A:2,0
8620 RMOVE @A:-0.06,-1
8630 PRINT @A:"2.0"
8640 FOR R1=3 TO 5
8650 RMOVE @A:1,0
8660 PRINT @A: USING 8670:R1
8670 IMAGE1D.1D
8680 NEXT R1
8690 MOVE @A:1.75,0
8700 RMOVE @A:-0.1,-0.2
8710 PRINT @A:"0"
8720 RMOVE @A:-0.18,0
8730 FOR R1=2 TO 20 STEP 2
```

```
8740 RMOVE @A:0,2
8750 PRINT @A: USING 8760:R1
8760 IMAGE2D.1D
8770 NEXT R1
8780 HOME @A:
8790 PRINT @A: USING 8800:"J ZETA vs. MACH No."
8800 IMAGE 31X,19A
8810 PRINT @A:"JJJJJJJJJJJJJJ"
8820 PRINT @A:"J ZETA"
8830 PRINT @A:"JJJJJJJJJJJJJJJ"
8840 PRINT @A: USING 8850:"MACH No."
8850 IMAGE38X,8A
8860 MOVE @A:2,0
8870 RMOVE @A:-0.017,0
8880 PRINT @A:"|"
8890 FOR R1=3 TO 5
8900 RMOVE @A:1,0
8910 PRINT @A:"|"
8920 NEXT R1
8930 MOVE @A:1.75,2
8940 IF A=32 THEN 8970
8950 RMOVE @A:0.04,-0.21
8960 GO TO 8980
8970 RMOVE @A:0.04,-0.29
8980 PRINT @A:"-"
8990 FOR R1=4 TO 20 STEP 2
9000 RMOVE @A:0,2
9010 PRINT @A:"-"
9020 NEXT R1
9030 MOVE @A:1.75,2
9040 RMOVE @A:-0.3,-0.2
9050 PRINT @A:"-"
9060 FOR R1=4 TO 9 STEP 2
9070 RMOVE @A:0,2
9080 PRINT @A:"-"
```

```
9090 NEXT R1
9100 MOVE @A:1.75,10
9110 RMOVE @A:-0.35,-0.2
9120 PRINT @A:"-"
9130 FOR R1=12 TO 20 STEP 2
9140 RMOVE @A:0,2
9150 PRINT @A:"-"
9160 NEXT R1
9170 MOVE @A:ABS(Q1(1)),ABS(Q(20,1))
9180 FOR R1=2 TO 7
9190 DRAW @A:ABS(Q1(R1)),ABS(Q(20,R1))
9200 NEXT R1
9210 PRINT "G"
9220 END
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